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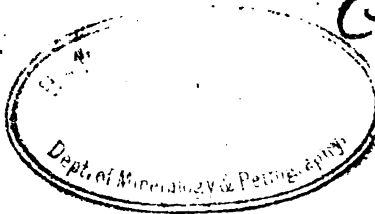


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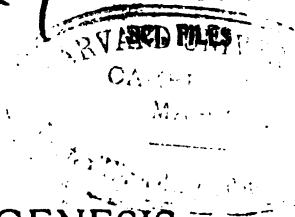
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THE PETROGRAPHY AND GENESIS OF THE SEDIMENTS OF THE UPPER CRETACEOUS OF MARYLAND

A DISSERTATION

Submitted to the Board of University Studies of The Johns Hopkins University
in conformity with the requirements for the degree of
Doctor of Philosophy

BY

MARCUS I. GOLDMAN

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THE PETROGRAPHY AND GENESIS OF THE SEDIMENTS OF THE UPPER CRETACEOUS OF MARYLAND

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INTRODUCTORY

The object of this chapter is to present the results of the detailed study and the mechanical and microscopical analysis of a few typical sediments from the Upper Cretaceous of Maryland. Work of this kind is merely an extension of petrography to the sedimentary rocks; yet it has hitherto been so little practised that most geologists hearing the term petrography think instinctively of crystalline rocks. This comment is made in order to forestall an attitude of mind towards what follows that is very general, namely the belief that after such an analysis of a sedimentary rock it is possible to determine the conditions under which the rock originated. That is, of course, the ultimate object of such work, yet it is no more implicitly the immediate result of the study of a given rock than the study of a given crystalline rock in the beginning of that science was the direct key to the origin of the rock—or is to-day, for that matter. If decades of study of conglomerates, whose composition is apparent to the unaided eye, leave many fundamental problems concerning this relatively simple type of rock still unsolved, it is not to be expected that microscopic knowledge of facts of the same kind about the sedimentary rocks of finer grain will suddenly reveal the conditions of their origin. In fact, for these finer-grained rocks, as for the conglomerates, field study of their larger geological characters, their variations vertically and horizontally, the form of the whole mass, its relations to adjacent beds, and other features must remain as important as the laboratory analysis. But a more detailed knowledge of the composition of the finer-grained sedi-

mentary rocks is desirable than the current terms, sandstone, shale, sandy shale, tuff, limestone, or even more circumscribed terms like chalk, greensand, etc., afford; and from the awakening interest in this subject it is safe to expect that before long every stratigraphic study of a limited region will contain descriptions of the composition of the sedimentary rocks involved. Every such study will bring out some significant facts regarding the origin of the particular rocks, but for a satisfactory final interpretation of the conditions under which the rock originated it will be necessary to have accumulated an extensive series of analyses of modern sediments of all possible varieties. Comparing then the ancient sediment with the modern ones, the conditions of whose origin will be more or less completely known, it will be possible by finding the modern sediment that is most similar to determine the conditions under which the ancient sediment in question was formed. On the other hand, the sediments of the past offer some opportunities to the investigator that are lacking in the modern. For in the subaqueous sediments of to-day only what is at the surface, or a few feet below, can be examined. Of the ancient sediments, however, it is possible to obtain sections in which the changes both vertical and lateral can be followed out, and thus knowledge gained which could be gathered from sediments in process of formation only through centuries of observation or through periods too long for consideration. Thus the two branches of the study must advance together, each throwing light on the facts of the other, and the two pointing out to each other the problems that require special attention.

It is this consideration that has led to the attempt to interpret freely the facts obtained in the present study in the belief that an investigation is valueless until some conclusion has been drawn from it, and that the investigator who has accumulated the facts is in the most advantageous position for interpreting them. These interpretations, however, are put forward most tentatively and with the greatest possible reservation.

While the published literature describing modern sediments is not inconsiderable,¹ it is not of much value for the Cretaceous sediments

¹ For a very full and up-to-date bibliography, see Andrée, K., *Ueber Sedimentbildung am Meeresboden* Geol. Rundschau, vol. 3, 1912, H 5/6, pp. 324-338.

because most of it deals with the deposits of the deeper ocean, little with the deposits near and adjacent to the mouths of rivers. Probably no investigator of modern sediments has had the geologic bearings of the study so forward in his mind as Thoulet, and it is his publications therefore, limited in extent though the work of one man must be, that are of most value to the geologist. Foremost in his work in this connection stands the recently published monograph, with colored maps, of the sediments of the Gulf of Lyon;¹ and the work of his pupil Sudry² on the Lagoon of Thau in the same region is, as subsequently pointed out, probably of particular bearing on the Matawan. (See especially sample 8, below.)

References to such studies as have been made of near-shore sediments will be found in Andrée's bibliography, but as far as I know the only systematic and continuous investigation of this type, and the only one whose results are expressed in the tangible form of a map is that by Thoulet of the Gulf of Lyon. In fact it is, I believe, the need for studies of this kind that inspired him to carry out the work.

THE METHOD OF ANALYSIS

In all essentials it is Thoulet's³ method of analysis that has been followed in this investigation.

In a general way three main types of procedure in the analysis of undurated sediments, whether ancient or modern, may be recognized. The first is the method of elutriation in which a separation, mainly of the clay and finer parts from the sand, is made by subjecting the sample to a rising current of water whose velocity is known and can be regulated. This method cannot be used, however, to subdivide material finer than $\frac{1}{4}$ mm., because finer particles settle too slowly to oppose any velocity of current

¹ Thoulet, J., *Etude bathylithologique des côtes du Golfe du Lion*. Annales de l'Inst. Océanograph., T. iv, Fasc. 6, Paris, 1912, 66 pp. Maps.

² Sudry, L., *L'Etang de Thau*. Ann. de l'Inst. Océanograph., T. 1, Fasc. 10, Monaco, 1910, 208 pp.

³ Thoulet, J., *Précis d'analyse des fonds sous-marins actuels et anciens*. Paris: Chapelot et Cie, 1907, 220 pp.—*Instructions pratiques pour l'établissement d'une carte bathymétrique-lithologique sous-marine*. Bull. de l'Inst. Océanograph., No. 169, Monaco, 1910, 29 pp.

that is practically attainable. Theoretically there would seem, however, possibilities of its unlimited extension to finer sizes in the centrifugal elutriator of Yoder,¹ in which the velocity that the particles oppose to the current is greatly increased by centrifugal force.

The second method, developed by Mitscherlich,² determines the relative internal surface of a soil. There are two distinct procedures for arriving at this quantity. The first is based on the fact that when water is brought into contact with a perfectly dry porous or powdered substance a certain heat is developed which is a function of the internal surface of the substance. The finer its particles the greater, of course, will this surface be, and the greater, therefore, the heat developed. In practice it is more convenient to adopt the second procedure, which determines the hygroscopicity of the substance, that is, the amount of water which the material will take up out of a saturated atmosphere. This quantity, as explained by Mitscherlich, is also supposed to have a definite relation to the internal surface.³

The third method, and the one most generally employed, is that of sieving the sands in conjunction with washing out the mud. It is to this group that the method of Thoulet belongs, as well as that of Murray, the U. S. Department of Agriculture, and others. To these methods are added certain accessory procedures (the essential part of some less generally practised methods) such as treatment in heavy liquid, by the electromagnet, with acids, etc.

There is no room for lengthy discussion of the relative values of these three methods; but for the purpose in hand the method by elutriation is theoretically and practically the most satisfactory,⁴ since it classifies the

¹ Yoder, P. A., Bull. No. 89, Utah Exper. Sta., 1904.

² Mitscherlich, E. A., *Bodenkunde*, Berlin, 1905, pp. 49-70.

³ An attempt to eliminate the effect of the internal surface of the *particles* (that is minute fissures or pores in them) has been made by Franz Scheefer: *Eine Methode zur Bestimmung der äusseren Bodenoberfläche*. Dissert. Königsberg. 1. Pr., 1909.

⁴ Thoulet, *Précis d'analyse* (op. cit.), 65-67.—Hilgard, E. W., *Soils*. 1906, pp. 90-93.—Ries, H., *Clays*. 1906, pp. 113-115.—Andrée, K., *Ueber Sedimentbildung am Meeresboden* (op. cit.), pp. 350, 351.

sediments by the relative settling velocities of their constituents, which is the significant factor in sedimentation, and, on account of the time allowed for working over the material in the elutriator, tends to classify them very successfully. Its defect is the great amount of distilled water, time, and attention it requires. The method of determining surface by heat of moistening or hygroscopicity seems to have the defect that it gives only a single value for each sample, so that sediments made up of very different proportions of the various sizes might yet give the same results. It is really a method that has much more significance for soils, for which it was devised, than for sediments to which it has, however, been very recently applied.¹

The method here followed, which is that of Thoulet with some modifications as will be noted, is essentially as follows: A large portion of the sample is first passed through sieves with respectively 3, 6, and 10 meshes to the inch, and the portion retained is classed as gravel, though concretions of these sizes should of course be separately considered. As a matter of fact, none of the samples contained any gravel that would not pass the 3-mesh sieve; very few, indeed, any gravel at all, and then only very little. As the material was dried at 105° it was necessary to know the proportion of gravel in such dried material, but it would not have been practical to dry the large portion required for gravel determination. The whole lot was therefore weighed merely air-dried, and at the same time a small portion weighed separately, dried for about eight hours at 105° C., and the percentage loss in drying determined. This loss was then applied to the large lot in which the gravel had been determined. For the rest of the analysis about 10 gm. of the sample, if necessary crushed somewhat in order to facilitate drying, is dried for about eight hours at a temperature maintained as nearly as possible at 105°. The sample was cooled in a dessicator and weighed rapidly; but the avidity with which the dried samples took up moisture gave an accuracy of not more than 5 mg. to 10 mg. The balance, moreover, that was used for the later

¹ Küppers, E., *Physikalische u. mineralogisch-geologische Untersuchung von Bodenproben aus Ost- u. Nordsee*. Wiss. Meeresuntersuch. Herausgeb. v. d. Kommiss. z. Untersuch. d. deutsch. Meere, etc., 1908, N. F., vol. x, pp. 1-11.

analyses did not have a reliable accuracy of more than 5 mg., which is the smallest unit to which weights were then recorded. The sample was next washed into an 8 oz. milk-sterilizing bottle with water and generally a little ammonia to help disintegrate the clay. The bottle was then shaken on a rotary shaker. This is simply an axis to which a board is fastened. The bottle is attached to the board at right angles to the axis with the middle of the bottle over the axis, so that when the axis is rotated the sediment and water, which should less than half fill the bottle, flop from one end of the bottle to the other twice in one revolution and by this jarring the sample disintegrates. The method seemed fairly effective; just how effective it is hard to say. Certainly in some of the samples there was a perceptible amount of clay granules, a little in all; they are mentioned in some of the analyses that follow, though they are not consistently recorded. But it is a question whether, in some cases at least, these clay granules are not an essential part of the sediment representing some kind of growth or concretion in the clay. That there is a possibility of the existence of such concretions is indicated by the round, clay-like granules with faint aggregate polarization that were found in a few of the samples (see sample 4) and believed to represent a stage intermediate between clay and glauconite. The uncertainty prevailing in the whole matter appears from the difference of opinion concerning the best method of disintegrating clay, Mitscherlich, *e. g.*, recommending that the sample be boiled some fifteen minutes, while others say that only luke-warm water should be used, because hot water coagulates the clays.

After being shaken ten to thirty hours, according to the apparent amount of clay in the sample, the material is washed out of the bottle into an evaporating dish of 12 cm. diameter. Here it is allowed to settle for a while, the mud decanted into a 1500 c. c. separating funnel, hot wash water added in the evaporating dish, the settling and decantation repeated, etc., several times. The length of time during which the material was allowed to settle varied for different samples and decreased for each successive decantation. If the sample was muddy the writer started with fifteen minutes, allowed ten minutes on the second settling and so on down, depending somewhat on the observed rate of clearing of the upper part of

the suspension. This appears to have been more time than Thoulet allowed, but it was probably on this account that very little residue from the material tapped from the separating funnel was obtained. Another slight adaptation of Thoulet's method consisted in fixing the time for the last settling at thirty seconds. That is, all the "sand" and "silt" had to settle in that time. This period was chosen on the basis of practical experience with the samples, which showed that the interval was sufficient to allow all but a certain cloudiness to settle out. In many samples, however, it was found that there was a sort of transition material which not only had a different appearance from the sand but also did not seem to settle with the same promptness as the sand, forming a sort of intermediate constituent. Microscopic examination justified this conclusion as, according to the constitution of the sample, irregular glauconitic fragments, limonitic fragments, or small clay flakes secondarily cemented appeared in this intermediate product. The determination of the amount of this product settling in thirty seconds but not in ten, was most unsatisfactory, since the quantity depended largely on the amount of water in the evaporating dish, the temperature of the water as affecting convection currents, and probably other factors, so that it was possible to wash back much of the material that had once been washed out, and vice versa, by continuing washing to keep on almost indefinitely washing out a little more silt from the sand. Any absolute value, of course, the portion settling between thirty and ten seconds has not in any case, since it represents no distinct pure product of any kind; but even its relative amount in different samples has no great precision. Actual results, however, as given in the following analyses, show that the differences in quantity are marked enough in some cases to indicate roughly the amount of this product, and thus to give some indication of the extent of the processes—in most cases probably subsequent to the formation of the sediment—which have produced it. Besides, since the material is finer grained than the extra fine sand, it is, in the end, according to Thoulet's classification, counted with the clay to determine the amount of mud, so that the separation of it does not affect the final numerical result.

The clay washings in the large separator funnel were allowed to settle for about half an hour, the settlings tapped and rewashed for any sand or silt that might have escaped the first washing. The amount, as indicated above, was usually very small. This method of separating sand and "clay" is in principal entirely similar to the method of the Bureau of Soils of the U. S. Department of Agriculture.¹ The use of the centrifuge by the Bureau of Soils merely hastens settling. Their method differs mainly in having definite size limits for the finer portions of "silt" and "clay." But the analysts of the Bureau of Soils themselves recognize that a perfect separation is never attained and that it is indeed theoretically possible only if all the particles treated have the same density and shape. But if other conditions remain constant the same result is attained by allowing the particles to settle a definite length of time through a fixed distance, so that theoretically the method of Thoulet, as used, gives the same results, even though time of settling instead of prevailing size of particles settled is used as the determining factor.

In general, it must be said, and is admitted by all students of sediments, that all such mechanical methods of separating sand and "clay," while they allow valuable comparison, are, from a scientific standpoint, still most unsatisfactory. It is now generally believed that the colloidal state, in which true clay may be assumed to be, is merely a certain state of subdivision between fairly definite limits (100μ to 10μ) in a continuous series from grains visible to the unaided eye to molecular solution. If this is so, then any separation of what might be called true clay, even if it were mechanically possible, would still be somewhat arbitrary. Moreover, there is some reason to doubt that in a natural sediment there actually exists such a continuous series rather than a mixture of certain definite constituents or groups of constituents each with its own size limits, the limits overlapping more or less.

The ideal solution of the problem would be to establish a curve showing the rate at which the settling of the constituents of a given sediment progresses. That different constituents can be differentiated in the finest

¹ U. S. Dept. Agric. Bureau of Soils, Bull. No. 24, 1904; Bull. No. 84, 1912.

portion by this method is indicated by the work of Mohr,¹ who carries his settling to periods of several weeks. But he too separates between arbitrary limits and his curve is therefore not continuous. Moreover, his results show that in the very finest portions some further differentiation could probably be made.

To go into a more detailed discussion of methods other than the mechanical for the differentiation of the constituents of argillaceous sediments would not be in place here. Reviews and discussions of such methods can be found in a paper by Stremme and Aarnio, "Die Bestimmung der anorganischen Kolloide," etc., *Zt. f. prakt. Geol.*, vol. xix, 1911, pp. 329-335, and van der Leeden und Schneider, "Ueber neuere Methoden der Bodenanalyse u. der Bestimm. der Kolloidstoffe im Boden," *Int. Mitt. f. Bodenkunde*, vol. ii, 1912, pp. 81-109, in which, among others, the method of Mitscherlich referred to above is discussed. There may also be much to be learned about the colloidal matter by the method of staining and microscopic study in which a beginning has been made by Hundeshagen.² But it may be said in conclusion that the analysis of clay-bearing sediments on a scientific basis, that is, on the basis of their natural constituents, has not yet been attained.

To continue the description of the method of analysis that has been employed in the present study, the clay suspension in the funnel was tapped into a large evaporating dish. Thoulet, who, working with fresh modern sediments, was not obliged to add ammonia to disintegrate, then added a few drops of alum solution to precipitate the clay, settled, siphoned off as much of the supernatant water as possible, and evaporated to dryness over a gentle heat. As ammonia was used in most of the present analyses, it had to be neutralized, which was done with hydrochloric acid. Performed at first approximately, this neutralization produced irregular results due doubtless to solution with an excess of acid, while to neutralize exactly was very tedious. Moreover, experiment with one sample showed

¹ Mohr, E. C. Jul., *Mechanische Bodenanalyse*. Bull. Dépt. de l'Agr. aux Indes Néerlandaises No. 41, Buitenzorg, 1910, 33 pp.—*Ergebnisse mech. Analysen tropischer Böden*. *Ibid.* No. 47, 1911, 73 pp.

² Hundeshagen, *Ueber die Anwendung organischer Farbstoffe zur diagnostischen Faerbung mineralischer Substrate*. Neues Jahrb. f. Min. etc. Beilage-Bd. xxviii, 1909, pp. 335-378.

that hot water dissolved a small portion of it, partly salts, partly a tough, almost white, colloidal substance, so that in the later analyses the whole quantity was evaporated down on a steam bath. The dried clay was scraped out of the dish with a steel spatula, a process which always involved some loss, partly from a small residue that adhered, partly from dust that was carried away. The clay was then dried for eight hours or more at about 105° C., cooled in a desiccator and weighed as rapidly as possible.

The sand separated from clay and silt was air-dried, weighed and then passed through a series of sives made of bolting cloth with approximately 30 (28), 60, 100 (97), and 200 meshes, respectively, to the inch.¹

Following, according to Thoulet's observations,² are the minimum sizes of the materials held back by the different sieves:

30.....	0.89 mm.	= Coarse sand.
60.....	0.45 "	= Medium sand.
100.....	0.26 "	= Fine sand.
		= Very fine sand.
200.....	0.04 "	= Extra fine sand.

Even this simple process of sieving is not quantitatively absolute which, as indicated above, is one of the reasons for preferring the elutriation method. The two causes are: most important of all that the grains are not round; a minor factor that the meshes, especially in the finer bolting cloths, are not uniform. As a result of the irregular form of the grains, very long grains with a short diameter less than the mesh opening will pass, and with prolonged shaking very many of them. The duration of the sieving is, therefore, a matter of accommodation based largely on personal judgment and experience. The procedure was to stop when the grains that came through were predominantly elongated. But this stage will be

¹ The figures in parentheses are the given meshes, according to trade numbering, which were the nearest that could be obtained. The actual mesh, according to measurement, is still somewhat different, in most cases fewer meshes per inch or larger openings. Professor Thoulet was, however, good enough to assure the author that these were quite accurate enough.

² Thoulet, J., *Précis d'analyse* (op. cit.), p. 64.

reached much sooner with the coarse than with the finer sizes. As the coarse material was, besides, usually less abundant the coarsest size was not generally shaken more than a minute, while the finest, that is, that on the 200-mesh sieve, when it was abundant required sometimes more than half an hour. The amount of shaking that each size received depended on the abundance of the material of that size, the sizes being successively removed from the nest of sieves, in the order of their fineness, while the finest was continued until observation, with the hand lens, of the material passed showed that predominantly elongated grains were coming through. The sieves were shaken by hand. The Department of Agriculture uses a mechanical shaker in which the sieves are left for about three minutes. Thoulet's principle is to continue shaking until a considerable shaking passes only a negligible amount of material,¹ as it would require an excessive length of time to produce an absolutely complete separation of the finer sizes. But his limit, which is also only approximate, agrees quite closely with the present, since, when dominantly elongated grains come through, the rate of separation is very slow. The products of sieving are weighed and put aside for study.

Finally the "very fine sands" are separated according to their specific gravity by means of Thoulet's solution, of a density slightly greater than 2.7. The most serious defect of this separation in the rocks studied was due to the glauconite. Fresh glauconite is lighter than all the feldspar and quartz, so that it remains in the light portion and can subsequently be in turn separated by its density. But in all the glauconitic rocks considered in the following the greater part of the glauconite sank with the "heavies" and was made up of grains ranging in density in many cases from less than 2.7 + to higher than 3.00. This is doubtless due to weathering effects. An exact determination of the amount of glauconite by weight was therefore impossible, and even the fairly close approximations that were obtainable with a solution of specific gravity of 3.00 and the electro-magnet to be mentioned below, are not quite comparable on account of the difference in density of the lots from different

¹ Thoulet, J., *Précis d'analyse* (op. cit.), p. 64.

samples. The importance of considering the glauconite separately is, however, evident, since in many of the samples it has been formed in place and not brought in like the rest of the material.

Except for separating the glauconite the electro-magnet plays no inherent part in the analysis of the samples. It has been used merely to segregate different minerals in order to facilitate the study of them. The magnetic permeability of different minerals is distinct, so that, by introducing various resistances in the circuit of the magnet, they can be segregated. Thoulet has for his magnet a table showing the current that will attract each mineral, but this varies so with the particular constitution, and doubtless also with the amount of decomposition of the mineral, that it affords only an approximate indication in practice. It was found most practical to try different strengths of current and examine the product with the hand lens, until a satisfactory separation was obtained. One of the most refractory minerals in both the gravity and magnetic separation is mica. While it tends to accumulate in certain portions, the segregation is always far from perfect, and, moreover, in transferring it there are always losses said to be due to static electric charges which cause it to adhere to the surfaces with which it comes in contact. This very static electric property can be used to separate it from other minerals, but this procedure has not been applied in the present study.

While the method thus described includes all the steps employed in a complete analysis it appeared, when the results began to accumulate, that some of the separations could not yield information of any value in certain sediments, or at least that more results of importance could be accumulated by not making each analysis so systematically complete; hence in a few of the later ones some of the steps are omitted.

The quantitative results of the mechanical analyses are represented in the diagrammatic form (pp. 169, 170) so effectively used by Mohr in the papers referred to above.¹ The construction of these diagrams is very

¹ While Mohr devised these diagrams quite independently, exactly the same type of diagram, differing only in scale, was used at an earlier date by J. A. Udden, "The mechanical composition of wind deposits." Augustana Library Publ. No. 1, 1898, 69 pp.

simple. The amount of each portion is represented by a vertical column of which the height corresponds to the percentage of the portion present in the whole sample. The columns are all of the same arbitrary width and the successive sizes are placed side by side, the vertical boundaries between them being the limit of size that separates them. Their significance may be most readily conceived by imagining the columns to represent small sample tubes containing the different portions and placed side by side in order of their size of grain.

Finally, mention must be made of a serious defect in the entire analysis of many samples, which arises from the abundance of carbonaceous organic matter present. Even a determination of it by quantitative analysis, if it did not involve an amount of time disproportionate to the advantage to be derived, would probably not give entirely accurate results. Keilhack¹ describes a common method of determination by burning off the carbonaceous matter, but this has so many defects that it scarcely seems worth using. It is probably largely on this account that the Bureau of Soils of the Department of Agriculture takes no cognizance of carbonaceous matter, which practice has been followed in the present study. However, a specific gravity separation might be used here to float off the carbonaceous matter, at least in the sands, with results of a degree of accuracy equal to that of the other separations. Certainly in some of the sediments that in the following pages have been called of the "delta" type the proportion of carbonaceous matter is so great that it interferes seriously with the value of the results of the analyses.

¹ Keilhack, *Lehrbuch der praktischen Geologie*, 1908, p. 540.

THE ANALYSES

SAMPLE NO. 1 (FIG. A, p. 169)

Serial number¹ : 7.
 Field number : 1st-10-2-1911.
 Formation : Magothy.
 Locality : Betterton.
 Appearance : A compact, massive, homogeneous, slightly greenish-gray, fine-grained, micaceous, argillaceous sand.

MECHANICAL ANALYSIS

Sample	11.040 gm.	
		Per cent of sample
Sands		73.4
Clay		26.1
		99.5
		Per cent of total sands
Coarse sand4
Medium sand		7.0
Fine sand		14.4
Very fine sand		45.3
Extra fine sand		33.2
Total		100.3
		Per cent of very fine sand
Light		89.3
Heavy		10.0
		99.3
		Per cent of total heavies
Attracted at 2000 ohms		43.65
S. G. > 3.002	15%	
S. G. < 3.002 (glauconite)	80.2% = 32.35% of heavies	
	= 3.20% of very fine	
Attracted at full current		37.10
S. G. < 3.002 (mica)	= 23.45% of heavies	
S. G. > 3.002 largely pyrite concretions		
Non-magnetic		1.70
Magnetite		17.40 ²
		99.85

DESCRIPTION OF PRODUCTS

A. UNDER THE HAND LENS³

There is very much carbonaceous plant matter which gives all the sands a dark, blackish-gray appearance.

The coarse, medium, and fine-grained sands all show a considerable proportion of well-rounded and smoothed quartz grains. They are all three speckled with the argillaceous grains described under the very fine light portion, the proportion of these increasing in the finer portions. Smooth limonitic grains occur in all of the portions, perhaps from the alteration of glauconite grains. Heavy minerals seem to be very scarce in these coarser portions though mica is scattered through the "fine-grained" sands.

¹ The serial number is the number given to the analysis when it was made, indicating the order in which the samples were taken up, hence not corresponding to the present order which is stratigraphic.

² High magnetite.

³ Magnification $\times 10$.

B. UNDER THE MICROSCOPE

I. *Very Fine Sand*(1) *Light*

Ratio of quartz to feldspar estimated 90 : 10.¹

With the light portion there is separated an abundance of grains of a translucent to opaque, humus-brown substance full of small dark granules. The substance is isotropic, index of refraction 1.55-1.56. It crushes plastically under the knife. Probably it is a combination of organic and inorganic colloidal matter, with inclusions of granules that may be both mineral and carbonaceous but are not fresh mineral grains.

(2) *Heavy*

Dominant.—Glaucinite in worn grains; percentage as given.

Abundant.—Magnetite, garnet, epidote, muscovite, pyrite in granular concretions.

Rarer.—Tourmaline, staurolite, chlorite, biotite, topaz, rutile, zircon, enstatite, kyanite, anatase (dumortierite?).

The well-rounded form of the magnetite grains is noteworthy.

II. *Finer Portions.*

The finer portions (extra fine, silt, and clay) show little of special interest. The clay is gray with a strong humus-brown stain, and contains unusually much of a dirty fibrous matter that is common in many of the samples.

Summary and Conclusions.—Noteworthy are:

- (1) The abundance and variety of heavy minerals.
- (2) The high percentage of magnetite with associated garnet and epidote.
- (3) The fact that the glauconite is all rounded, *i. e.*, reworked.
- (4) The rounded clay-like grains. These may be merely undisintegrated clay, though their abundance would seem to indicate some concretionary process, perhaps the first stages in the formation of glauconite, as will be explained in the general discussion of glauconite (see p. 176 below). The abundance of pyrite in the sample, however, suggests that pyrite may have something to do with the formation of these granules, though I believe such a process has not hitherto been recognized.
- (5) The pyrite concretions. Pyrite concretions are, under certain conditions, formed in waters in which abundant organic matter is decomposing.
- (6) The lack of sorting indicated by the abundance of several different sizes of sand and the high percentage of magnetite and garnet.

¹The ratio of quartz to feldspar was determined by making several counts, in different parts of the slide, of all the grains in the field of view of a No. 4 objective and determining the number of these that were feldspars. The feldspars were rather readily picked out, following Thoulet, with the aid of a liquid of index 1.548 (the mean index of quartz), checked when necessary by determining the optical figure. The average as will be seen, is always given to the nearest 5 units. The relative sizes of the grains was not considered, so that the results have no absolute quantitative value. They do serve, however, to indicate the relative abundance in different samples.

SAMPLE NO. 2 (FIG. B, p. 169)

Serial number : 10.

Field number : 14-10-2-1911.

Formation : Magothy.

Locality : Betterton.

Appearance : A hard, blue-gray, faintly laminated clay in layers about 1 inch thick with sandy partings.

MECHANICAL ANALYSIS

Sample	14.050 gm.	
		Per cent of sample
Sands	14.2	
Silt	13.2	
Clay	66.8	
Total	94.2	
		Per cent of total sands
Coarse sand	0.7	
Medium sand	6.6	
Fine sand	6.3	
Very fine sand	43.9	
Extra fine sand	42.7	
Total	100.2	
		Per cent of fine sand
Light	87.5	
Heavy	12.4	
Total	99.9	

DESCRIPTION OF PRODUCTS

A. UNDER THE HAND LENS

The coarse portion is only carbonaceous matter; the medium-grained contains, in addition, small rounded pyrite nodules, grains and flakes of argillaceous matter, but as primary minerals only a few flakes of mica. The fine-grained contains more of the clay grains, and mica more abundant and in greater variety, there being chlorite as well as muscovite.

B. UNDER THE MICROSCOPE

I. *Very Fine Sand*(1) *Light*

Quartz : feldspar = 85 : 15.

Besides feldspar and quartz carbonaceous fragments and argillaceous grains as in the coarser portions, are important constituents. These two constituents are, in fact, so abundant that they interfered with the study of the quartz and feldspar. A portion was therefore incinerated and with the aid of this incinerated portion the following facts could be determined.

The plant fragments appear in two forms, one black and opaque, the other brown, translucent, and generally showing some organic structure. The incinerated portion turned from black to red. Under the microscope it was then found that most of the opaque black fragments had disappeared but the brown translucent remained with all their structure, having apparently only turned red. It may be that some of the translucent had also disappeared but the essential point is that many of them, at least, were evidently permeated, or perhaps partly replaced, by some iron salt which on incineration preserved the form of the original plant fragment.

Here too the clay grains, found in the other portions as well, could be studied under the microscope. The facts about them may therefore be summarized. They are round

or flaky in form. The smaller sizes are translucent, of a humus-brown color, filled with small opaque flakes and grains. They crush plastically but the crushed portion reveals no new characters.

Essentially they are probably true clay and their appearance is that of the greater part of what is separated as clay. But it is important to know whether they are merely undissintegrated portions of clay, or whether they are minute concretions. The flaky form of many of them supports this latter hypothesis, suggesting their formation in moulds such as the plant fragments might afford. For the present, however, the question must remain undecided.

(2) Heavy

The heavy minerals are:

Abundant.—Muscovite, chlorite, serpentine.

Rarer.—Tourmaline, glauconite, garnet.

Essentially the heavy portion is muscovite, with some chlorite and serpentine, tourmaline and garnet being exceedingly rare. Of glauconite there are very few grains, many of them weathered yellow.

II. Silt

Dark dirty, brownish-black, micaceous. The dark color appears to be due mainly to the great amount of black carbonaceous matter which is probably responsible for the high percentage of silt separated from this sample, though the large proportion of the finest-grained sands is probably also a factor in this result. The carbonaceous matter not only contributes to the silt itself but also catches up many grains of fine sand which are floated off with it. There is very little argillaceous matter and that in irregular foci, not in the rounded grains noted in the very fine light portion.

Summary and Conclusions.—Noteworthy are:

(1) The very small proportion of sands and the large proportion of clay.

(2) The very high proportion of carbonaceous matter.

(3) The granules of argillaceous matter and the pyrite concretions as in sample 1. The sample seems to be, like sample 1, high in heavy minerals, but this is deceptive since micas are the principal constituent of the heavy portion, and these in spite of their specific gravity are classed, in the processes of sedimentation, rather with the light and fine-grained minerals.

SAMPLES NO. 1 AND NO. 2

General Summary and Conclusions.—While sample 2 is markedly different from sample 1 in the much lower percentage of sand, in the general dominance of the fine-grained materials, and in the scarcity of heavy minerals other than mica, it still has in common with it certain features that are essential. Foremost among these is the wide range of size in the sands; for while these are dominantly finer-grained they do not show that dominance of any one size that is characteristic of the most typical marine sediments which have been subjected to the sorting action of strong waves. This is at once apparent from an inspection of the diagrams of these two

sediments (A) and (B), p. 169, with the diagrams on p. 170, representing various types of deposits. The high percentage of carbonaceous matter is also a characteristic of both samples. Both contain concretionary pyrite grains or small nodules, and in both there are the peculiar clay granules that have been noted.

Before interpretation of the beds is attempted their manner of occurrence in the field should be taken into account. This is characterized above all by the rapid and rather extreme alternation of the beds between the two types, sandy and argillaceous, as fairly well represented by these two samples. Carbonaceous matter is conspicuous, also micaceous beds, while thin films of whitish sand between the beds are a characteristic peculiarity.

The mechanical analyses of sediments, that are represented on p. 170, are not numerous enough nor sufficiently correlated with the exact conditions of their formation to justify direct matching of the above analyses with them. They illustrate certain general factors in sedimentation rather than definite types of sediment, and this first discussion of them may therefore be made a general introduction.

The principal factors in the diagrams are: (1) The *maximum*, that is, the predominant portion. Both the extent to which it exceeds the other portions as an indication of the degree of sorting of the sediment, and the size which it represents as indicating the strength of the sorting agent are significant. (2) The *sharpness of the "curve,"* as Mohr calls it, on each side of the maximum, that is, the extent to which the maximum exceeds the portions on both sides of it. (3) The general form of the curve, especially whether it shows more than one maximum. This last feature, however, while theoretically important is evidently very much influenced by the degree and limits of subdivision of the sample. In the diagrams of these Cretaceous sediments the only second maximum is that representing the clay portion, but that this would in most cases probably disappear is indicated by the analyses given by Mohr.¹ He makes many subdivisions of the portion classed as clay in Thoulet's method of analysis, with the result that there is often a steady fall of the curve through these portions.

¹ Mohr, E. C. Jul., *Ergebnisse mech. analysen*, etc. (op. cit.).

An examination of the diagrams on p. 170 leads to the recognition of the following general effect of different conditions and agents on the diagrams. Most conspicuous is the difference in the degree of sorting or sizing. The most complete sizing is produced by strong waves and by wind action (p. 170, figs. A, C, J, K, L). Off-shore marine sediments (p. 170, fig. C) are as well sorted as beach sands, differing only in having the maximum in a finer size. A similar difference in the maximum appears between dune sands of temperate regions (p. 170, fig. J) and those of tropical regions (K, L), and though this might be due to a difference in the part of the dunes from which the different samples were taken, it is also quite possible that the prevailing winds of these tropical regions are stronger.

But while the deposits found respectively under the influence of winds and of strong waves thus agree in their perfection of sizing, they also show a certain difference in that, in the product of wave action, after the maximum the largest portion is the next finest material, while in the eolian deposit the next coarsest is generally the largest.¹

The lagoonal deposits may be taken as representing in general deposits in a small body of water in which there is much weaker wave-action and less room for the horizontal separation of sizes than in the ocean. Consequently sizing is less perfect (p. 170, figs. E, F).

River sediments in addition to being poorly sized tend, as explained by Mohr,² to show an abrupt rise of the curve on the left and a gentle fall on the right. That is, sedimentation of streams is likely to take place from a sudden change in velocity; hence all of the coarsest and much of the finer material that it has been able to carry to the point of sedimentation will suddenly drop out. This is well illustrated by the typical diagram, M, p. 170.

Delta deposits show a combination of this stream effect with a certain amount of sorting as can be seen in diagrams D and I, pl. II, but the sorting effect of wave action appears very rapidly away from the edge of a marine delta.³

¹ See further, Udden, J. A., *The mechanical composition of wind deposits*. Augustana Library Publ. No. 1, 1898.

² Mohr, E. C. Jul., *Ergebnisse mechanischer analysen*, etc. (op. cit.), p. 35.

³ See some of the analyses in Thoulet's study of the Gulf of Lyon, cited above.

This general view of sedimentation diagrams affords a sufficient basis for the special consideration of the sediments discussed in this chapter. To turn then to samples 1 and 2.

No detailed field and laboratory study of delta sediments has been published, to the writer's knowledge; but from what little can be learned of such deposits it appears that the beds from which samples 1 and 2 are taken show many of the characteristics of delta formations. In their field relations the rapid alternation, the extremes represented, the thin partings of sand, and the abundance of carbonaceous matter support this view. And consideration of the conditions of sedimentation in a delta leads to the same conclusion, for, according to the principle laid down by Johannes Walther, only such facies can succeed each other as can exist side by side. Now, in a delta there is a sharp difference between the channels and the waters lying to the side of them, so that in one there would be deposited relatively coarse sand, while in the other fine sediments would slowly settle. Then sudden changes of channel, such as would be produced by high water in a region with the extremely low relief of a delta, would bring two such facies into vertical succession, producing the type of section seen at this locality. The sandy partings, on the other hand, would result merely from the passing conditions of a single flood without a change of channel.

The mechanical analyses, also, fall in with this general view. To be sure, A, p. 169 (= sample 1) and E, p. 170 (= a lagoon sediment) show a similarity which amounts almost to identity. But the quiet, open bodies of water in a delta would, in their conditions of sedimentation, be entirely equivalent to a lagoon, like that from which E, p. 170, is derived. In B, p. 169, the upper shaded portions of the five left-hand columns represent the analysis recalculated to a basis of 100 after subtracting the clay and silt, and in this form the similarity of the diagram to a stream sediment like M, p. 170, with the abrupt rise of the curve on the left and the poor sorting, is strikingly brought out. Both these analyses therefore fit in well with the conditions that would exist in a broad delta.

Formation of pyrite is another characteristic of such deposits. It is due, as noted above (Sample No. 1, *Summary and Conclusions*), to the H_2S

liberated by the decay of organic matter, but requires slow circulation of the water in which the H_2S is liberated, so that the gas may not be carried off as quickly as it is formed. Thus pyrite grains are characteristic of the deeper, stagnant water of the Black Sea, and the writer has a carbonized fragment of wood collected from the East River at New York, encrusted with pyrite. The pyrite grains in the coarsest sediment (sample 1) were therefore probably carried into it from some stagnant portion of the delta invaded by a change of current.

A peculiar feature, perhaps related to the pyrite formation, was noted in the "light" portion of sample No. 2. Black opaque, and brown translucent carbonaceous matter was so abundant that a portion was incinerated to free it from these particles. The effect of incineration was to give the sample a reddish color, but a large part of the organic fragments remained. Evidently then they had been impregnated or partly replaced by some iron salt, very possibly by pyrite.

Some such process may also account for the abundant clay granules noted in both samples. The flat form of many of these is against the assumption that they are merely undecomposed clay fragments, since in that case they would more probably have been developed, in shaking, with rounded form. The flat shape indicates rather that they were formed in some mould with that shape, perhaps in the carbonaceous plant fragments, where they may well have shared in the impregnation with an iron salt shown by the plant fragments themselves. This problem, however, requires further study. The facts are, as far as I know, new.

Of great geologic interest, though not bearing immediately on the conditions of origin of this deposit, is the occurrence of glauconite in both of the samples. It shows that conditions favorable to the formation of glauconite existed previously even farther inland than this region. Since there is no trace of a glauconitic deposit, older than these beds, known in the region, there must have been a considerable transgression in early Magothy or pre-Magothy times of which the deposits have been subsequently entirely eroded.

It is further worth noting, though without much more extensive field study the fact must not be given too much weight, that this particular

facies of the Magothy occurs here at the head of Chesapeake Bay, therefore just below the mouth of the present Susquehanna. It points to the possible existence of that stream in Cretaceous times.

SAMPLE NO. 3 (FIG. C, p. 169)

Serial number : 13.

Field number : 3-7-13-1911.

Formation : Matawan.

Locality : Chesapeake and Delaware Canal.

Appearance : Typical Matawan ; black glauconitic clay with little mica.

MECHANICAL ANALYSIS

Sample	8.967 gm.
	Per cent of sample
Sands ¹	64.8
Silt	6.3
Clay	27.0
Total	98.1
	Per cent of total sands
Coarse sand	4.8
Medium sand	5.3
Fine sand	5.7
Very fine sand	59.4
Extra fine sand	24.8
Total	100.0 ¹
	Per cent of very fine sand
Light	71.2
Heavy	28.3
Total	97.5

MAGNETIC SEPARATION

	Per cent of heavies	
Attracted at 2000 ohms (glauconite) ²	63.7	=16.8% of very fine
Attracted at full current.....	28.6	
Non-magnetic	0.5	} = 8.3% of very fine
Magnetite	2.9	
Total	95.7	
	Per cent of 2000-ohms portion	
Attracted at 2000 ohms, S. G. > 3.002.....	12.0	
Attracted at 2000 ohms, S. G. < 3.002 (glauconite) ²	87.1	=14.6% of very fine
Total	99.1	

¹ Total sands by summation of parts.

² The separation with the solution of density 3.002 was made to facilitate study of the rare heavy minerals. A small part of the glauconite came down with the heavy minerals while much mica remained floating with the glauconite. The value for percentage of glauconite after the separation at density 3.002 is, however, probably nearer right than before this separation, so that *glauconite* may be taken as about 15% of the very fine sand, leaving about 11% of true heavy minerals.

DESCRIPTION OF PRODUCTS

A. UNDER THE HAND LENS

I. Coarse Sand

- (a) Fairly well rounded grains of quartz mostly white opaque, almost all, however, much pitted and corroded as if by solution.
- (b) Next in abundance are rounded concretions formed of grains of fresh-looking glauconite, quartz, etc., cemented by limonitic matter.
- (c) Some of the quartz is of the black granular concretionary type (cf. Sample No. 13) suggesting secondary origin in the sediment.

II. Medium Sand

- (a) Angular quartz grains predominate, though there are still some very well rounded; there is also more glassy, less opaque quartz.
- (b) The *glauconite* is mostly in rounded grains; most of those that are not rounded suggest by the irregularity of their form a secondary concretionary origin from botryoidal grains. There are a very few normal botryoidal grains all somewhat rounded. The proportion of glauconite is small.
- (c) There are limonitic sand concretions as in the coarse sand but more rough and irregular, less rounded.
- (d) Considerable white mica.
- (e) Black carbonaceous fragments.
- (f) Shell (?) fragments stained brown.

III. Fine Sand

Its general appearance is dark greenish-black, speckled.

- (a) Quartz predominantly glassy and angular.
- (b) Glauconite as in preceding but much more abundant.
- (c) Limonitic sand concretions as in preceding.
- (d) Much white mica.
- (e) Many black carbonaceous fragments.

IV. Very Fine Sand

General appearance much like the fine sand.

V. Extra Fine Sand

Dark blackish-gray. Appear much like the preceding portion.

B. UNDER THE MICROSCOPE

I. Very Fine Sand

(1) Light

Quartz : feldspar = 90 : 10

The feldspars appear unusually decomposed. No plagioclase was found.

There is little glauconite and mica left.

Both quartz and feldspar show much ocherous staining.

A grain was noted made up of individual grains of quartz differently oriented in a cloudy quartz cement of homogeneous orientation, believed to be derived from quartzite.

(2) Heavy

- (a) Attracted at 2000 ohms heavier than 3.002.

The abundant minerals, in the approximate order of their frequency, are:

Abundant.—Glauconite in translucent to nearly opaque olive-green grains, chlorite, biotite unusually abundant, epidote.

Rarer.—Garnet, tourmaline, muscovite, staurolite, rutile.

- (b) Attracted at 2000 ohms lighter than 3.002.

Not especially studied. Almost pure glauconite with some mica.

- (c) Full-current product.

A brownish-yellow, micaceous sand.

Abundant.—Muscovite, chlorite, quartz. This is doubtless separated here on account of its heavy ocherous stain.

Rarer.—Tourmaline, epidote, biotite, asbestos (?).

(d) Non-magnetic.

Zircon and enstatite, about equally abundant. Kyanite very rare.

(e) Attracted by permanent magnet: Mainly magnetite but with much chlorite, some biotite, and a little glauconite. Magnetite in very angular grains.

II. Extra Fine Sand

Mainly quartz with some glauconite and mica.

III. Silt

Dark gray with a yellowish tint. Many ilmonite flakes. Much mica. A fibrous serpentinous mineral common.

IV. Clay

Yellowish showing much ilmonitic matter. Much fibrous matter.

Summary and Conclusions.—The most striking feature of this bed is the evidence of *reworking* of the material in it. Thus, except in the coarsest sand, there is almost no glauconite in primary botryoidal form, the grains being mostly rounded.

I think the ocherous stain of the grains throughout, the sand-ocher concretions, and the weathered condition of the feldspars may be interpreted in the same way, for it does not seem as though such products could be formed in a sediment as argillaceous as this while, moreover, the bed itself remained black and free from ocherous stain. It seems more probable that they originated in a more open-textured glauconitic sand exposed to atmospheric agents before its constituents were reworked and redeposited in this bed.

The other principal feature is the evidence that seems to me to point to something like a delta facies for this bed. The factors indicating this are:

1. The mechanical composition of the sediment as shown in C, p. 169 (*cf.* D and J, p. 170). The material is seen to be unsorted, all sizes being well represented, though the three finest largely predominate. This poor sorting suggests a small body of water, either a lagoon or a quiet open stretch of water in a delta, while the sharp rise of the curve from the fine to the very fine sand with a slow drop to the right has been shown in the general discussion of these diagrams to be characteristic of stream sediments.

2. The abundance of mica.

3. Abundance of carbonaceous matter.

4. The high percentage of heavy minerals, especially the rather large proportion of magnetite.

Finally, there are to be especially noted the black concretionary quartz grains which, for the present, I shall not discuss (see p. 175, below).

SAMPLE NO. 4 (FIG. D, p. 169)

Serial number : 14.

Field number : 4-7-13-1911.

Formation : Matawan.

Locality : Chesapeake and Delaware Canal.

Appearance : A fairly light-gray, very micaceous, fine-grained, argillaceous sand; no glauconite apparent.

MECHANICAL ANALYSIS

Sample	7.510 gm.
	Per cent of sample
Sands	68.1
Silt	1.1
Clay	29.5
Total	98.7
	Per cent of total sands
Coarse sand	0.4
Medium sand	1.4
Fine sand	3.1
Very fine sand	72.8
Extra fine sand	21.4
Total	99.1
	Per cent of very fine sand
Light	88.4
Heavy	9.8
Total	98.2

MAGNETIC SEPARATION

Magnetic	98.1
Non-magnetic }	1.9
Magnetite }	
Total	100.0

DESCRIPTION OF PRODUCTS

A. UNDER THE HAND LENS

I. Coarse Sand

Consists of 13 flakes of white mica and one very lustrous black carbonaceous flake.

II. Medium Sand

Almost all mica, mostly white with some brown and pale green flakes. Carbonaceous grains. No quartz could be found.

III. Fine Sand

Same composition as the preceding.

IV. Very Fine Sand

See microscopic study of parts.

V. Extra Fine Sand

Dirty green micaceous sand.

B. UNDER THE MICROSCOPE*I. Very Fine Sand*

(1) Light

Quartz : feldspar=85 : 15

General appearance silvery-gray, micaceous.

The quartz grains are of two kinds:

(a) Glassy grains with more or less inclusions.

(b) Rough, pitted, granular fragments with a greenish tinge. The green-stained variety is, however, rare.

Glaucouite occurs in pale, olive-green, transparent, rounded grains, very fresh looking.

All kinds of feldspars except plagioclases were noted, in general appearing rather rough and weathered but not kaolinized.

(2) Heavy

(a) Magnetic

General appearance light greenish-drab, with much muscovite and a striking absence of glauconite and generally of dark minerals.

Dominant.—Muscovite, chlorite, glauconite, serpentine.

Subsidiary.—Garnet, tourmaline, biotite, calcite (?).

The biotite appears much decomposed, some of it full of black grains (magnetite ?).

(b) Non-magnetic

Dominant.—Zircon.

Rare.—Enstatite, garnet, calcite, kyanite.

II. Extra Fine Sand

Appearance. Silver-gray with a greenish tinge.

(1) Much glauconite in round grains, green, semi-transparent, fresh-looking.

(2) Round, brownish grains specked with black. They look exactly like clay but polarize faintly. They differ from the glauconite in that the glauconite is clear without the black, granular inclusions. (Cf. Silt (III) below.)¹

III. Silt

(1) Much *argillaceous* material in flakes or globules.

(2) Rounded grains of transparent, granular, *clay-like* material of which the globular form and aggregate polarization suggest that it may be incipient glauconite.

(3) Pale, yellowish-green, transparent glauconite.

(4) A few pale yellow, transparent, angular, granular, non-polarizing flakes, probably of limonite.

(5) Mineral grains are common.

(6) There are large flakes of mica.

(7) Black carbonaceous matter.

IV. Clay

Appearance blue-gray.

Pretty fine clay with much fibrous material which though dirty brown and clay-like in appearance yet polarizes.

The amorphous-looking clay also polarizes as an aggregate, probably on account of minute included mineral fragments. Individual mineral grains are, however, unusually scarce.

Summary and Conclusions.—Two characters are particularly striking in this sediment.

(1) The foremost is the abundance of mica apparent in the original specimen, but supplemented in the analysis by the high percentage of the

¹ Note that the clay was also found to have aggregate polarization though that may have been due to included mineral fragments.

fine-grained portions with which it goes in sedimentation, and the low proportion of heavy minerals, yet without a very high percentage of clay.

(2) The second important feature is the apparent secondary character of the glauconite. There are no botryoidal grains, all those that occur being rounded, and occurring only in the very fine-grained and finer portions.

Furthermore there is to be noted:

- (3) The abundance of carbonaceous matter.
- (4) The weathered condition of the feldspars.
- (5) The abundance of biotite.

Of great general interest as bearing on the problem of the origin of glauconite are the rounded grains of substance having the appearance of clay and yet polarizing, suggesting a transition form between clay and glauconite. I shall take these up later in a general discussion of the glauconite below. (See p. 176, below).

SAMPLE NO. 5 (FIG. E, p. 169)

Serial number : 11.
Field number : 1-7-13-1911.
Formation : Matawan.
Locality : Chesapeake and Delaware Canal.
Appearance : Yellow, micaceous and slightly glauconitic sand.

MECHANICAL ANALYSIS

Sample	8.395 gm.	
		Per cent of
		sample
Sands ¹	92.6	
"Clay" (mainly yellow ocher)	7.7	
Total	100.3	
		Per cent of
		total sands
Coarse sand	0.2	
Medium sand	2.8	
Fine sand	24.9	
Very fine sand	69.0	
Extra fine sand	3.1	
Total	100.0 ¹	
		Per cent of
		very fine sand
Light	90.4	
Heavy	8.6	
Total	99.0	

¹ Total sands by summation of parts.

MAGNETIC SEPARATION

	Per cent of total heavies
Attracted at 2000 ohms (glauconite).....	52.2
Attracted at 1000 ohms.....	9.8
Attracted at 200 ohms (mica).....	35.9
Total	97.9

Magnetite and non-magnetite each about 1 per cent.

DESCRIPTION OF PRODUCTS

A. UNDER THE HAND LENS

I. Coarse Sand

Eight grains of quartz, of which two are well rounded, the others fractured, more or less angular and rough. Here again it seems as if the roughness might in part be due to solution acting on the grains.

II. Medium Sand

Striking for the angularity of the quartz grains, though their surface is nevertheless glossy, again suggesting the action of solution. Yellowish-green glauconite with primary botryoidal form is present. There is some ochreous staining.

II. Fine Sand

In general the same as the medium sands with perhaps slightly more glauconite.

IV. Very Fine Sand

In this size the glauconite grains are in general worn, and there are many limonitic grains.

V. Extra Fine Sand

Very limonitic.

I. Very Fine Sand

I. Very Fine

(1) Light

Quartz : feldspar = 90 : 10.

The grains of both quartz and feldspar have much glauconite adhering to their surfaces and penetrating into their fissures. There are some rusty, round grains of glauconite present.

(2) Heavy

(a) Attracted at 2000 Ohms

Mostly *glauconite* in rounded grains, some translucent brown, others semi-opaque, dirty, greenish-yellow.

Accessory.—Chlorite, epidote, tourmaline.

(b) Attracted at 1000 Ohms

Has a golden brown slightly green-tinged color, from an abundance of completely *yellow glauconite*.

Accessory.—Tourmaline, epidote, biotite.

(c) Attracted at 200 Ohms

Appearance golden-brown, micaceous. Almost all *biotite* generally pale yellow.

Accessory.—Serpentine, tourmaline.

(d) Full Current

Mainly mica and some enstatite.

(e) Non-magnetic

Most Common.—Enstatite.

Rarer.—Zircon, rutile.

Summary of Heavy Minerals

Dominant.—Glaucinite, biotite.

Rarer.—Chlorite, epidote, muscovite, magnetite, tourmaline, serpentine, enstatite, zircon, rutile.

II. Clay

Very limonitic but also with a considerable fibrous portion.

Summary and Conclusions.—In spite of the fact that this is a rather pure sand with little clay the proportion of the finer sizes of sand, especially of the very fine, is remarkably large.

The proportion of *heavy minerals* is insignificant; for if from the small percentage that settled at 2.7 + is deducted the glauconite there remains principally biotite, which in spite of its specific gravity is not properly regarded as a heavy mineral.

The botryoidal form of the glauconite in this sample indicates that it has been formed in place. The large proportion of glauconite is unusual.

SAMPLE NO. 6 (FIG. F, p. 169)

Serial number : 12.

Field number : 2-7-13-1911.

Formation : Matawan.

Locality : Chesapeake and Delaware Canal.

Appearance : Typical Matawan of Maryland. A dark-gray, friable, fine-grained, somewhat argillaceous sand, showing glauconite under the hand lens.

MECHANICAL ANALYSIS

Sample	9.867 gm.
	Per cent of sample
Sands	75.4
Silt	2.2
Clay	21.2
Total	98.8
	Per cent of total sands
Coarse sand	1.7
Medium sand	9.3
Fine sand	32.6
Very fine sand	47.7
Extra fine sand	8.4
Total	99.7
	Per cent of very fine sand
Light	72.3
Heavy	26.3
Total	98.6

It was not at first intended to weigh the products of magnetic separation, so that a large amount of the glauconitic portion was taken out for various purposes before it was decided to weigh. From the weights of the other magnetic products, however, the weight of glauconite may be approximated :

Glaucinite about 95% of heavy portion=about 25% of very fine sand.

DESCRIPTION OF PRODUCTS

A. UNDER THE HAND LENS

I. Coarse Sand

Contains one grain of fine gravel. Most of the quartz grains are milky, opaque, some of them stained green; doubtless by glauconite. A few of the grains are *perfectly rounded* and polished like wind-blown sand. The rest are subrounded or rough but many of them with the glossy "solution" surface. A grain of clay with included sand grains looks like a *concretion* (cf. Sample No. 3). Only one grain of quartz shows *limonitic staining*. There are some transparent, cellular, leaf-like plant fragments.

II. Medium Sand

Differs from the coarse sand:

- (1) in containing a few grains of fresh-looking, green, botryoidal glauconite,
- (2) in containing a very few grains of heavy minerals including a little mica.

III. Fine Sand

This portion has a "pepper and salt" appearance due to the abundance of glauconite mixed with the quartz. While most of the quartz is very angular there are, as in the preceding portions, still a number of very well rounded grains. Most of the glauconite is very fresh looking, but a good deal of it nevertheless shows rounding by wear.

IV. Very Fine Sand

Contains more glauconite than the preceding, but is otherwise very similar.

V. Extra Fine Sand

Dark greenish-gray, micaceous.

VI. Silt

Light greenish-gray, micaceous.

B. UNDER THE MICROSCOPE

I. Very Fine Sand

(1) Light

Quartz : feldspar = 90 : 10.

The striking features are:

- (a) The absence of limonitic staining.
- (b) The small amount of glauconite along cleavage cracks and fissures.

(2) Heavy

- (a) Attracted at 10,000 Ohms

As indicated above this is principally glauconite. The minerals identified are: garnet, tourmaline, deep blue chlorite, staurolite, epidote, muscovite, biotite, rutile.

- (b) Attracted at Full Current

Dominant.—Muscovite, serpentine.

Common.—Tourmaline, rutile.

Rare.—Biotite, epidote, enstatite, quartz with rutile inclusions.

(c) Non-magnetic

Enstatite most common with much zircon.

II. Extra Fine Sand

The glauconite in this portion is in rounded grains.

III. Silt

Here the glauconite is in irregular flakes. The product therefore has a distinct qualitative though not a quantitative significance.

IV. Clay

A normal, pure-looking, blue-gray clay showing under the microscope few mineral grains, but also few of the polarizing fibrous particles which appear to be characteristic of most of the clays; it is mainly amorphous brown matter.

Summary and Conclusions.—This is a typical, normal sample of the Matawan of this region and as such offers little requiring special comment here. The condition of the glauconite in it seems to prove that the glauconite is primary, so that this sediment represents lithologic conditions under which glauconite may be formed. There has been very little secondary action of any kind as is proved by the absence of limonitic and of glauconitic staining, while the sharpness with which the separation of clay and sand could be made confirms this conclusion.

The seeming argillaceous concretions (see coarse and medium-grained sand) should be noted. Noteworthy, also, is the small amount of carbonaceous matter.

SAMPLES NOS. 3, 4, 5, AND 6

General Summary and Conclusions.—These four samples are from one locality and section and were taken in order to find what the analyses might show to supplement their field relations. The results are interesting enough to justify a special discussion here.

Following is the field section, beginning at the top:

	Feet.
(5) A capping of post-Cretaceous gravel and diagonally (current) bedded sand.	
(4) Very glauconitic, yellow, somewhat argillaceous sand.....	2-3
Sharp contact with	
(3) Very glauconitic, gray, argillaceous sand (Sample 6).....	6
Bed 3 seems to grade into bed 2 although an appearance of a sharp contact is given by a thin line of limonitic staining separating the two beds.	
(2) A light yellow, glauconitic sand containing little clay in the upper part but growing more argillaceous and gray towards the bottom (Sample 5).....	12
About 2 feet at the top are filled with tubes $\frac{1}{4}$ inch in diameter, running through the sand in all directions and containing very glauconitic sand.	
Sharp contact with	
(1) A dark gray, micaceous, glauconitic, argillaceous sand, growing less micaceous and more glauconitic towards the lower part. Exposed to base of section.....	5
(Sample 4 = upper micaceous part.)	
(Sample 3 = lower glauconitic part.)	

Considering the field section and the analyses together we find that they fall very naturally into two distinct types.

A. That represented by samples 3 and 4 = bed 1; micaceous material, with reworked glauconite and much carbonaceous material.

B. That represented by samples 5 and 6 = beds 2 and 3; typical Matawan beds, with glauconite evidently formed in place.

The resemblance of type A to the Magothy as at Betterton (see samples 1 and 2) is apparent, with the marked difference, however, that there is here no rapid alternation vertically in the character of the beds. Without paleontological evidence it is moreover not certain that bed 1 here is not Magothy, though just as there was evidently glauconite formed before the formation of the similar beds of the Magothy at Betterton, so there is no apparent reason why in the midst of the glauconite formation of the Matawan there should not be a facies similar to the Magothy.

While the present state of our knowledge of sediments does not allow a definite classification of these beds, I think it is evident that bed 1 represents more of the river delta type of deposit while beds 2, 3 and 4 represent the more quiet conditions under which glauconite is formed.

Considering these two groups we find at first glance a remarkable lack of difference in the relative proportion of sand and clay and in the percentage of very fine sand, but the striking difference is in the distribution of the other sizes. Thus in what are tentatively called the delta type there is very little material coarser than the very fine, this portion forming the maximum and appearing in the diagrams (figs. C, D, p. 169) with the abruptness characteristic of delta and stream sediments (*cf.* figs. D, I, J, p. 170); at the same time the abundant extra fine gives a transition to the clay—a feature which from these same diagrams on p. 170 is seen to belong more to this type of sediments.

Samples 5 and 6 (E, F, p. 169) on the other hand, while they show some marked differences from each other, have in common a clear antithesis to samples 3 and 4 in the two features just enumerated, that is, there is a more gradual gradation through the coarser sizes to the maximum in the

very fine, and a more sudden drop to the fine, features which from the diagrams on p. 170 are seen to differentiate open-water sediments from those of deltas or streams (compare figs. A, C, E, with D, I, J, p. 170).

Furthermore, while at first sight the proportion of heavy minerals shows no consistent difference in the two groups, it is found when glauconite is deducted that the percentage of heavy minerals in the glauconitic type is only 2%-3%, while in the "delta" type it is about 8%. Besides, the deduction of glauconite is much more significant in the glauconitic type, since here it is not an imported mineral. But while in its fresh condition glauconite has generally a specific gravity considerably less than 2.7, it is questionable whether the material in bed 1 had not already become partly decomposed, and thus actually a heavy mineral, before it was transported into bed 1. In sample 3, which is the portion of bed 1 in which glauconite is particularly abundant, both the glauconite itself and the ocherous staining of other minerals support this belief, as I have indicated in the discussion of that sample.

As to the history of the succession that can now be worked out for this section I should first question the field determination of a sharp contact between beds 1 and 2. On the contrary, since bed 1 is very argillaceous, and bed 2, while it grows more sandy towards the top, is also argillaceous at its base, it seems more probable that there was here a transition, though it may have been quite sudden.

Then we have in bed 1 the evidence for the exposure of an older glauconitic bed to the atmosphere with partial decomposition of the glauconite and ocherous staining of the other grains. This bed was attacked by the stream which deposited in its delta the material of bed 1, while through deepening of the water or reduction in grade of the supplying stream the material gradually grew finer. Ultimately by a continuation of this evolution the waters became quiet and clear, and favorable to the formation of glauconite. Under these circumstances beds 2 and 3 (samples 5 and 6) were formed, but the conditions controlling were, as noted above, not in all respects similar for the two beds. A glance at E and F, p. 169, and comparison with the figures on p. 170 show at once the essential grouping of

the differences. Bed 2 (sample 5, fig. E, p. 169) is of the well-sorted type produced by strong wave action or by wind; bed 3 (sample 6, fig. F, p. 169) shows a remarkable resemblance to the poorly-sorted lagoonal type represented in E, p. 170.

The facies of bed 3 (sample 6) is therefore easily recognized; it was formed not in the open sea but in a more enclosed body of water, a lagoon, or perhaps an estuary or an arm of a bay like Chesapeake Bay of to-day. But bed 2 (sample 5) is harder to place. Mere comparison of its diagram (E, p. 169) with the diagrams on p. 170 shows a resemblance to diagram J even more striking than that of F, p. 169, to E, p. 170. This does not necessarily mean that bed 2 was wind-deposited. Its general conforming to the rest of the section with transition probably at bottom as well as at top (in any case a more argillaceous composition in its lower part), and the fact that no striking rounding of the quartz grains was noted, are against this interpretation. The discrepancies can be adjusted if it be assumed that the difference between diagrams of wave-sorted material, like C, p. 170, and wind-sorted material like J, p. 170, is more fundamental than mere difference between action of water and air, and represents rather the different effects of wave and current action. That is, a current of water might produce the same sorting shown in E, p. 169, as was produced in J, p. 170, by a current of air.

Theoretical considerations lend support to this conclusion. For the action of waves consists essentially in a prolonged *working over* of material of a certain maximum degree of coarseness depending on the average uniform conditions under which material is supplied to them. From this they tend to eliminate all the finer material, producing a concentration of the coarsest. Even though their strength is constantly fluctuating the end result of their work is the product essentially of their *maximum force*. But a current is an actively *depositing* agent, and while it will also tend to eliminate all material that is fine enough to be carried by it, the sorting it produces will be rather the result of its *mean* strength corresponding to a certain fineness of material which would be accumulated too fast to be accessible for reworking by its maximum strength. Hence the coarsest material brought in during periods of maximum

strength would represent a minor admixture to a larger quantity of its average size. In this way would result the difference between marine and wind sediments shown by diagrams C and J, p. 170, in that in the marine deposits, which are essentially the products of wave action, the next largest quantity after the maximum is in the next finest material, while in dune sands, which are essentially current-deposits, it is in the next coarsest. That is to say, in wave-worked material there would be an admixture of finer material which had escaped the maximum wave strength, while in current-deposits the products of their greatest strength would appear as the admixture and the finer material produced by their average strength would survive as the maximum.

That some sorting action and not the advent of coarser material is responsible for the presence of a smaller amount of very fine sand in bed 3 (sample 6, F, p. 169) than in bed 2 (sample 5, E, p. 169) appears from the fact that there is actually more of coarse, medium, and fine sand together in the argillaceous sample 6 than in the sandy sample 5. It may still be, in view of our imperfect knowledge of the mechanical composition of sediments, that in spite of the divergence of sample 5 from typical wave-worked sediments it is nevertheless the product of deposition in more open water, perhaps as a result of the deepening suggested above, and that as deposition continued, or possibly uplift of the region replaced subsidence, the area in which this section was deposited became cut off as a lagoon or estuary. But the interpretation that the difference is due to a local current which passed over the area when the lower bed (bed 2) was being deposited, but disappeared before the deposition of the upper bed (bed 3), seems the more probable.

The position of the line of limonite staining between beds 2 and 3 is probably determined by distance from the surface and porosity combined. Such lines are common throughout the region and by their wavy form and lack of relation to the lithology show that they are secondary and formed by circulating ground waters.

Bed 4 may represent shallowing of the water, but as it is at the top of the section its sandy yellow appearance is more probably due to alteration, so that in the absence of an analysis nothing definite can be said about it.

SAMPLE NO. 7 (FIG. G, p. 169)

Serial number : 15.

Field number : 3-9-12-1911.

Formation : Matawan.

Locality : Camp Fox, Chesapeake and Delaware Canal.

Appearance : Friable, sandy, gray-white marl, speckled with glauconite.

MECHANICAL ANALYSIS

Sample	8.404 gm.
Treated with dilute HCl to dissolve lime.	
	Per cent of sample
Lime-free residue	80.2
Lime (by difference)	19.8
Total	100.0
	Per cent of lime-free residue
Sands	87.8
Silt	0.9
Clay (by difference)	11.3
Total	100.0
	Per cent of total sands
Coarse sand	0.2
Medium sand	16.2
Fine sand	60.6
Very fine sand	20.0
Extra fine sand	2.8
Total	99.8
	Per cent of very fine sand
Light	57.8
Heavy	42.2
Total	99.5

MAGNETIC SEPARATION

	Per cent of total heavies	
Attracted at 2000 ohms (glauconite)	86.0	= 36.2% of very fine
Attracted at full current	7.5	
Non-magnetic	0.4	} = 6% of very fine
Magnetite	3.0	
Total	96.9	
	Per cent of 2000-ohms portion.	
Attracted at 2000 ohms, S. G. > 3.002	13.9	
Attracted at 2000 ohms, S. G. < 3.002 (glauconite) ¹	86.1	= 74.0% of heavy = 31.2% of very fine
Total	100.0	

¹ A minimum value for glauconite in this portion, since some glauconite came down with the part heavier than 3.002. There are, on the other hand, some heavy minerals especially mica in the part that floated at 3.002 though their weight is doubtless less than that of the glauconite that settled. Good approximations are probably:
 Glauconite 80% of heavy = 35% of very fine,
 which leaves actual heavy minerals about 7% of the very fine.

DESCRIPTION OF THE PRODUCTS

A. UNDER THE HAND LENS

I. *Lime-free Residue*

This separates in water into two very distinct parts:

- (1) Very glauconitic clear sands.
- (2) Dark brown clay (probably with considerable limonite) which floats on top.

II. *Coarse Sand*

Eight grains of quartz with glossy, pitted surfaces; one of them is stained green; one is sugary and stained brown. Some leaf fragments.

III. *Medium Sand*

Glossy, angular quartz; some sugary grains stained brown as in II; almost no grains stained green. Very fresh botryoidal glauconite; some rounded grains of glauconite.

IV. *Fine Sand*

Much of the glauconite is rounded and more than in III is faded yellowish; otherwise the glauconite is as in III. There is very little mica.

V. *Very Fine Sand*

The glauconite is almost all rounded, much of it weathered yellowish. The grains of quartz are all angular.

VI. *Extra Fine Sand*

General appearance green. The glauconite is half yellowish, half fresh, blue-green.

B. UNDER THE MICROSCOPE

I. *Very Fine Sand*(1) *Light*

Quartz : feldspar = 90 : 10.

The determination of the proportion of feldspars present is made difficult by the presence of minerals in various stages of decomposition, towards a mass with complex aggregate polarization, which may be derived from feldspars. Difficulties are also afforded by cloudy grains which may be quartzite. Most of the feldspars are much weathered. A grain of plagioclase was noted. There is much irregular glauconitic staining of grains, and glauconite in thick seams along cleavage cracks. Many grains of glauconite are present.

(2) *Heavy*

(a) Attracted at 2000 Ohms, S. G. > 3.002

More than half *glauconite*. *Magnetite* largest part of remainder, many of the grains well rounded. *Red garnet* a little less common than *magnetite*. *Epidote* and *staurolite* rather common. Some *chlorite*. Green *zircon* (?).

(b) Attracted at 2000 Ohms, S. G. < 3.002

Almost pure *glauconite*, in well rounded or botryoidal grains, opaque to slightly translucent, free from coarse-granular inclusions. The botryoidal grains are very scarce. There is, in addition, a very little *muscovite* and quartz.

(c) Attracted at Full Current

Tourmaline, *rutile*, *augite*, *biotite*, *muscovite*, green *zircon*, *chlorite*, *glauconite*. The *glauconite* in this portion is in rough, irregular grains, cloudy to opaque, mostly full of black mineral grains. Many of the grains that look like *chlorite* are found to have undulatory to aggregate polarization indicating that they are in a transition stage from or to *chlorite*. In view of the fact that *glauconite* is itself believed to be one of the *chlorites* this may be of significance for the formation of *glauconite*. Two small, remarkably *spherical* grains of *quartz* are noteworthy.

(d) *Non-magnetic*

Most common *enstatite*, *zircon*, *augite*, *hornblende*, *apatite*, *rutile*, and *andalusite* (?). The good preservation of the crystal form of the *rutile* is striking.

(c) Magnetite

Very angular, with a few rounded grains. Much glauconite included. Some garnet.

II. Extra Fine Sand

Largely glauconite in irregular grains.

III. Silt

Nothing of interest. Mineral grains, much mica, glauconite. Very few limonite flakes.

Summary and Conclusions.—This sample, which may be considered typical of the facies of the Matawan in this neighborhood, is interesting, first of all for its marly character, that is for the combination in it of clay and high lime content with glauconite. With the high lime content goes a great richness in fossils. I can see no reason for considering this difference other than primary, since there is no factor apparent that would preserve the lime here more than in other occurrences. Of course it is assumed that foraminifera originally occurred in all the primary glauconitic rocks, but their shells would form merely a thin coating on the individual glauconitic grains, not a calcareous argillaceous mass through which the glauconite might be distributed. It is, therefore, fair to assume that the bed was formed under conditions unusually favorable to the life of neritic shell bearing forms.

The diagram for the sample (K, p. 169) is that of a rather normal open-water off-shore sediment, with sorting, however, less perfect than in marine off-shore deposits.

In the mineral composition there is noteworthy the occurrence of several minerals scarce or very rare in other samples, especially hornblende, augite, apatite, and andalusite. The unusually good preservation of the crystal form of rutile indicates its derivation from nearby.

The general fresh condition of the glauconite is characteristic for the sample. In view of this fact it does not seem probable that the irregular grains of glauconite with inclusions represent a decomposition product, for in that case some intermediate stages would be expected. More probably, therefore, they are a distinct type of glauconitic product. Their form and occurrence suggest analogies with the limonitic flakes in many samples, which are probably mainly small encrustations loosened from the grains on which they occur. In the same way these would be loosened flakes of glauconite encrustations, such as are found on the surface and in

cracks of many quartz and feldspar grains in this and other samples. While the botryoidal grains of glauconite were presumably formed in the shells of foraminifera, these encrustations and stains must have been formed unenclosed in the midst of the sediment. Though the manner of their formation is not yet clear this difference in the conditions under which they developed may well account for their different appearance.

Concerning the complex chloritic grains, also in the full-current product, I have no interpretation to suggest, but merely draw attention to them again here.

SAMPLE NO. 8 (FIG. H, p. 189)

Serial number : 16.

Field number : 5-9-12-1911.

Formation : Matawan or Monmouth.

Locality : Camp Fox, Chesapeake and Delaware Canal.

Appearance : Fine-grained, dark-green, speckled sand, considerably weathered and stained with limonite.

MECHANICAL ANALYSIS

Sample	7.700 gm.	
		Per cent of sample
Sands	88.8	
Silt	0.6	
Clay	11.1	
Total	100.5	
		Per cent of total sands
Coarse sand	0.5	
Medium sand	27.2	
Fine sand	42.8	
Very fine sand	26.3	
Extra fine sand	2.9	
Total	99.7	
		Per cent of very fine sand
Light	63.2	
Heavy	36.5	
Total	99.7	

MAGNETIC SEPARATION

		Per cent of total heavies
Attracted at 1500 ohms.....	90.5	
Attracted at full current.....	4.4	
Non-magnetic	0.2	
Magnetite	1.8	
Total	96.9	
		Per cent of 1500-ohms portion
Attracted at 1500 ohms, S. G. > 3.002.....	6.2	
Attracted at 1500 ohms, S. G. < 3.002 (glauconite)...	94.8 = 85.8% of heavy = 31.3% of very fine	
Total	101.0	

DESCRIPTION OF PRODUCTS

A. UNDER THE HAND LENS

I. Coarse Sand

Quartz grains so strongly pitted that their original form is obscured. Many of them are stained yellow. Besides the quartz there are brown, opaque, limonitic grains. One of these has the characteristic form of an agglomerated glauconite grain. There are two little concretions of sand, one in a dark blackish matrix, the other in a yellow, limonitic cement like the concretions in sample 3.

II. Medium Sand

Yellowish-green, specked with dark glauconite. The quartz is angular. Glauconite botryoidal. Smooth reddish-brown grains of which one or two were seen in the coarse sand are more common here. Some of them have a conchoidal fracture like limestone, and the fresh surface is pinkish-white. Others, probably partly decomposed, are brittle and pale yellow inside. They dissolve with effervescence in cold dilute hydrochloric acid. They are therefore probably either siderite, or calcite or aragonite stained by limonite. Their smooth rounded form and glossy surface suggest their origin in connection with some organic process.

III. Fine Sand

Like II except that there appears to be somewhat more glauconite and that most of the glauconite is in rounded grains.

IV. Very Fine Sand

Like preceding but much of the glauconite turned yellow.

B. UNDER THE MICROSCOPE

I. Light

Quartz : feldspar = 90 : 10.

General appearance greenish with some grains of glauconite and some limonitic stain. There is much glauconite along the cleavage of feldspars and in irregular staining patches on the outside of the grains. Some of the glauconite grains seem to show almost their original botryoidal form.

II. Heavy

(1) Attracted at 1500 Ohms, S. G. > 3.002

Dominant.—Magnetite, garnet (red and colorless), epidote, staurolite.

Rarer.—Tourmaline, chlorite, chloritoid (1 grain).

(2) Attracted at 1500 Ohms, S. G. < 3.002

Practically pure glauconite. Opaque and densely clouded grains with a yellowish tinge. They do not show coarse granular inclusions only a fine disseminated powder responsible, at least in part, for the cloudiness.

(3) Attracted at Full Current

Under the hand lens much rusted glauconite and other rust-colored minerals. Chlorite, muscovite, biotite, tourmaline, andalusite, augite, apatite, rutile, enstatite, zircon, kyanite, aragonite. Particularly characteristic are two types of grains to which the brown color of the portion is largely due. These are:

(a) A brown granular, non-polarizing grain which looks like what I have been calling limonite but which dissolves completely in dilute acid, with strong effervescence.

(b) A brown, translucent mineral occurring in irregular forms but also in parallel sided (prismatic) grains. The grains of irregular shape have imperfect, more or less undulatory extinction, but that of the prismatic grains is generally perfect and parallel. These grains also dissolve with effervescence in dilute acid, but seemingly not always completely, leaving a skeleton or nucleus.

The only explanation I have for (b) is that it is aragonite stained with limonite. The form and undulatory extinction of some of the fragments of this type suggest that they are parts of the shells of some animal—(a) is probably something similar, but I cannot explain its non-polarizing. The matter requires further study. Most of the flakes of mica and grains of decomposed minerals in this portion are stained green.

(4) Non-magnetic

Dominant.—Zircon, enstatite, apatite, in about equal amounts.

Rare.—Kyanite, rutile.

(5) Magnetite

Almost all in angular grains. Contains, besides, much slightly cloudy, yellowish-green glauconite. Some muscovite and garnet.

III. *Extra Fine Sand*

General appearance drab olive-green. Light minerals and glauconite in about equal proportions, with of course some rare minerals. The glauconite is both in rounded grains and in irregular fragments. There are some limonitic flakes.

IV. *Silt*

Limonitic flakes are prominent in this portion. There is less glauconite than in the extra fine-grained.

V. *Clay*

General appearance faint yellowish-gray, with not as much limonitic material as might be expected from the character of the rock. There is a considerable amount of the fibrous material which has been found characteristic of the clays.

SAMPLES NOS. 7 AND 8

General Summary and Conclusions.—The significance of sample 8 is largely in its relation to sample 7, so that it must first of all be considered in connection with this.

In the field the upper part of the marly glauconite sand from which sample 7 is taken was found to be full of pycnodont shells much worn, bored, and sometimes broken. This condition seems to indicate a period of exposure in shallow coastal water. Together with the sharp contact between this bed and the overlying, it proves a disconformity, at least locally.

The most striking fact about their relations is the almost perfect similarity in every respect except the lime content.

The sands in the upper bed (sample 7, fig. L, p. 169) are a little coarser and a little less perfectly sorted, but in the proportions of sand and clay, the general relation of the different sizes and the mineral content there is remarkable agreement. This extends even to the proportion of glauconite, which is almost exactly the same in the two beds. The only

difference is a secondary one that might be expected from the loose texture of the upper bed as against the compactness of the lower—namely, more limonitic matter in the upper. But it is very interesting to note that the glauconitic staining of mineral grains is not one of these secondary differences; nor the apparently altered opaque condition of the glauconite; which would thus seem to have been produced before the beds were emerged.

The two beds are thus so intimately related that if it were not for the accumulation of oysters in the top of the lower bed one would be led to assume continuous deposition. The essential difference is in the presence of abundant shells in the lower bed. It may be that the somewhat less agitated condition of the water in which the upper bed was deposited produced enough difference to make the area relatively unfavorable for the animal life which had abounded at the time the lower bed was formed. In any case the change appears to have been a subtle one.

SAMPLE NO. 9 (FIG. 1, p. 169)

Serial number : 19.

Field number : 17-9-28-1911.

Formation : Matawan.

Locality : Grove Point, mouth of Sassafraz River.

Appearance : Dark blackish-gray, fine-grained, micaceous, argillaceous sand with some scattered pebbles of fine-grained white quartz too scarce to have been caught in analysis.

MECHANICAL ANALYSIS

Sample	10.780 gm.	
		Per cent of sample
Sands	68.5	
Silt	2.1	
Clay	28.2	
Total	98.8	
		Per cent of total sands
Coarse sand	0.1	
Medium sand	0.4	
Fine sand	0.5	
Very fine sand	45.1	
Extra fine sand	53.0	
Total	99.1	
		Per cent of very fine sand
Light	91.4	
Heavy	5.6	
Total	97.0	

DESCRIPTION OF PRODUCTS

A. UNDER THE HAND LENS

I. Coarse Sand

Nine grains of milky quartz, some very rough, others rounded but strongly corroded. Several black carbonaceous flakes.

II. Medium Sand

Much like the coarse sand, with some glossy quartz in small angular grains, with more well rounded grains than the coarse sand, some mica, and much black carbonaceous matter mainly fragments of wood.

III. Fine Sand

Very much white mica and some chlorite. Most of the quartz is sharply angular but there are still some rounded grains. There are a few grains of heavy minerals, zircon, garnet, etc. Very much black carbonaceous matter as above.

IV. Very Fine Sand

Silver-gray with much mica and much fine carbonaceous matter. It is darker than the extra fine sand which apparently contains little carbonaceous matter.

B. UNDER THE MICROSCOPE

I. Very Fine Sand

(1) Light

Quartz : feldspar = 95+ : 5—.

It is hard to count the feldspars in this sample on account of the aggregate polarization of many grains which probably are decomposing feldspars but which cannot be identified. However, this should be regarded as an essential character of the rock and with the low percentage of feldspar shows that the *decay of the feldspars* had advanced far in this sample.

There is a great variety of feldspars present including some plagioclase.

The material is characterized by a dirty yellowish staining of the grains neither ocherous nor glauconitic but in a very few cases looking like remnants of a glauconitic stain. There are a few chloritic grains which, however, show aggregate, incomplete, or undulatory polarization, and some very pale greenish-yellow without noticeable birefringence.

There is considerable muscovite. No glauconite was found.

(2) Heavy ¹

(a) Magnetic

Dominantly muscovite with abundant chlorite and biotite. A very little garnet and tourmaline were found.

(b) Non-magnetic

Zircon.

II. Extra Fine Sand

Fine grayish-white sand. Quite pure, unstained quartz and feldspar with some scattered carbon and a few grains of green chlorite in evidence.

III. Silt

Darker gray, more micaceous than II. Under the microscope like the extra fine sand with more carbonaceous matter and more mica. There are many of the pale yellow chloritic grains that were observed in the very fine light portion.

IV. Clay

Pure blue-gray. Unusually rich in the fibrous, dirty-colored, polarizing material found so characteristic of the clays.

¹ This was the first sample examined for minerals so that the identification is probably not complete.

Summary and Conclusion.—The prominence of fine-grained material in the sample and the abundant mica and carbonaceous matter recall the Magothy formation of this region, but it differs from the Magothy in the field by occurring in massive beds, while the Magothy is thin-bedded or laminated. Moreover, there are marked differences in the composition of the material. Its diagram (G, p. 169) is peculiar in that while it shows almost only fine material the nearly equal proportion of the different sizes is striking. The abrupt rise of the "curve" on the right is a character, as already noted, of stream sediments, but the stream sediments shown in diagram M, p. 170, do not show so large an admixture of clay to sands. In the study of this bed in the field a peculiar mottled effect of light and dark-gray portions, which on close examination were found generally to consist of cylindrical tubes of the light sand running at random in more or less vertical directions through a matrix of the dark sand, was noted. They did not resemble worn tubes which are generally solid cylinders, not, like these, hollow cylinders filled with the dark material that surrounds them. The interpretation which suggested itself at the time was that the sand had been deposited in the midst of reeds which after their decay had been replaced by clay but had bleached the sand around them. I think this clue leads to a diagram which while not exactly like G, p. 169, yet explains some of its anomalies. On p. 170 are two diagrams, G and H, of materials from the same general lithologic belt in the Lagoon of Thau, but H representing sediment deposited in a portion of the lagoon overgrown with water plants. The effect of such a tangle of plants would naturally be to produce less perfect sorting, and this is what we see in comparing diagrams G and H, p. 170, the extra fine portion having been increased at the expense of the clay but without an increase, even with a slight decrease, in the relative amounts of the portions coarser than extra fine. This low proportion of these coarser sizes would naturally result from their interception in the same way by the nearer-shore portions of the same plant areas. As a result of these processes then, a diagram like I, p. 169, though of the general lagoonal type, comes to resemble more specifically diagram H, p. 170, the extra fine sand and a part of the clay having been

increased by the holding action of a plant tangle so as to equalize their amount more with that of the very fine sand.

Combining this conclusion with the stream character indicated by the sharp rise of the "curve" on the left we have here a sediment deposited where a stream discharged into or flowed through the midst of plants in some small quiet body of water. Regarding the grains of quartz in the coarser sizes it should be borne in mind, not only for this sample but for all others, that there is always the possibility, especially in near-shore deposits such as these, that they have been brought in by wind. Thoulet¹ has shown the transporting power of wind, a strong gale (13 m. per sec.) being able to carry grains over 1 mm. in diameter, and, while these theoretical deductions are somewhat invalidated by Udden's² observations on wind deposits and his theoretical deduction that the effective force of the wind is only that which survives the friction of the earth's surface (probably never exceeding 3 miles an hour), it is yet indicated by observation³ as well as theory that an occasional coarse grain is brought in by winds. This agent therefore may well be accountable for the few grains even of the coarsest size found in this sample; that a current which transports material so very predominantly of the finest sizes should ever bring in these few scattered coarse grains seems very improbable, while it is reasonable to believe that an occasional strong wind would be quite able to supply them.

The rounding of these grains which, as noted above, is a marked characteristic of many of the grains of the fine sand is a feature more common in wind-blown than in water-transported sand, and therefore also lends support to this conclusion.

There is another feature of the sample, however, which is perhaps of even greater stratigraphic interest than the evidence of the conditions of its deposition. That is, the indications of weathering which its material bears, and the absence of glauconite. Since other deposits of this type

¹ Thoulet, J., *Analyse d'une poussière éolienne de Monaco, etc. Annales de l'Inst. Océanograph.* Tome III, Fasc. 2, Paris, 1911, 8 pp.

² Udden, J. A., *Op. cit.*

³ See Thoulet's observations, in the paper just cited, on sediments off the Azores supposed to have been brought by wind from the Desert of Sahara.

have been studied and the material in them not found so weathered it is justifiable to conclude that the sands of this sample were weathered before they entered the bed. This would presumably be the interval corresponding to a disconformity between the Magothy and Matawan during which sedimentary beds from which this material was derived were exposed to atmospheric weathering. The absence of glauconite also tends to confirm this belief, for while the beds contributing it to the Magothy (in which it is all reworked) might have just become exhausted with the closing of the Magothy, it is very improbable that the two phenomena would so closely agree in time, and much more probable that there had been a considerable interval during which either the glauconitic beds were completely eroded, or the glauconite entirely decomposed.

SAMPLE NO. 10 (FIG. J, p. 169)

Serial number : 4.

Field number : 4-9-28-1911.

Formation : Matawan just below the contact with the Monmouth, or basal Monmouth.

Locality : Sassafra River.

Appearance : A greenish-yellow, lumpy, crumbly sand, full of limonite spots and with some tinges of a lavender-brown clay. Under the hand lens it shows rather angular quartz sand with small, rusty grains of glauconite; and throughout the mass, but seemingly related to the glauconite, an epidote-colored stain. On a freshly-broken surface the lavender-brown argillaceous matter is evident.

MECHANICAL ANALYSIS

Sample for gravel ¹	205.075 gm.
	Per cent of sample
Medium gravel	0.4
Fine gravel	1.6
Sands	98.0
Total	100.0 ¹
Sample for sands and clay.....	10.236 gm.
	Per cent of sample
Sands ²	62.1
Silt	3.7
Clay	24.1
Total	89.9
	Per cent of total sands
Coarse sand	1.1
Medium sand	37.6
Fine sand	43.6
Very fine sand	14.2
Extra fine sand.....	3.5
Total	100.0 ²

¹ By summation of parts.² Total sands by summation of parts.

	Per cent of very fine sand
Light	94.6
Heavy	5.4
Total	100.0

DESCRIPTION OF PRODUCTS

A. UNDER THE HAND LENS

I. Coarse Sand

Grains of glassy quartz and some opaque, subrounded but showing a glossy, pitted surface as if solution had acted on them. The opaque grains, which are probably a saccharoidal quartz of quartzitic origin, are penetrated by an ochreous stain of which there are traces on some of the other grains. There are almost no grains that look as if they had been well rounded before solution acted on them.

II. Medium Sand

Much like the coarse, but there seems to be a somewhat larger number of rounded grains in it.

III. Fine Sand

Like preceding.

B. UNDER THE MICROSCOPE

I. Very Fine

(1) Light

Quartz : feldspar = 90 : 10.

The feldspars are striking for the predominance of fresh grains (probably mostly sanidine) among them. Feldspars showing the characteristic kaolonisation along cleavage cracks are very rare. Some were observed that had small bands of glauconite arranged along cleavage cracks.

(2) Heavy

Among the heavy minerals glauconite generally in weathered, brown, opaque grains is the most common.

Common.—Magnetite unusually abundant; garnet very common; epidote.

Rarer.—Tourmaline, chlorite, staurolite, rutile, zircon, enstatite, kyanite. Striking in this rock are the varieties of zircon; besides the usual colorless to pale hyacinth there are grass-green and smoke-brown zircons.

II Silt

The silt in this case differs markedly from the very fine sand in that much of the limonite present has gone into the silt, while the very fine sand is made up mostly of fresh primary mineral grains.

III Clay

The product called clay is here, as in all samples in which much limonite has been formed by weathering, a very impure product containing, in addition to true primary matter, much of this secondary limonite.

Summary and Conclusions.—The principal features of this sample are:

(1) The prominence of the coarser sizes of sand and the marked lack of sorting. The diagram (I, p. 169) is distinctly of the lagoonal type (*cf.* A, p. 169, and E, p. 170) and therefore requires no special comment. It may well represent the basal deposit of a transgressing estuary of a large bay like Chesapeake Bay, or of a lagoonal body of water.

- (2) The lack of rounding of the sand.
- (3) The very small proportion of heavy minerals.
- (4) The relative abundance of magnetite and garnet in the heavy portions, a character which seems to be correlated with coarseness and poor sorting.
- (5) The scarcity of mica.
- (6) The reworked glauconite.
- (7) The freshness of the feldspars.

This bed differs markedly from most occurrences of Matawan mainly in the coarseness of its grain, and in the absence of black clay. It occurs in the following section as recorded in the field, beginning at the top:

- 5. Monmouth glauconite sand penetrated by limonitic crusts.
- 4. A marked $\frac{1}{4}$ inch limonitic crust separating 5 from
- 3. A sandy transition zone (sample 10) to
- 2. Argillaceous Matawan with finely disseminated limonitic crusts.
- 1. Fresh argillaceous Matawan.

In the absence of analyses of the underlying and overlying beds this sample loses much of its significance, yet the field relations, and general knowledge of the two formations between which it lies, in conjunction with its own analysis, seem to point pretty clearly to its interpretation. The author is then inclined to regard it rather as a basal part of the Monmouth reworked from the underlying Matawan than as upper Matawan. The general coarseness of the material (which is of the character of a basal bed), the reworked condition of the glauconite, and the weathered condition of the upper part of the Matawan, as shown by the limonite crusts in bed 2, support this view. The distinction is rather essential. If the bed belonged to the Matawan it would represent a gradual shallowing, forming a transition to the coarser sediments of the Monmouth. By the other interpretation there was an interval after Matawan time during which the upper part of the Matawan was weathered, then a transgression of the Monmouth which accumulated a basal layer of coarse material and *reworked glauconite* before the typical Monmouth conditions with the formation of primary glauconite were reached.

SAMPLE NO. 11 (FIG. K, p. 169)

Serial number : 18.

Field number : 5-10-28-1911.

Formation : Monmouth.

Locality : Seat Pleasant, Prince George's County, east of D. C. Line.

Appearance : A fairly light gray-black, fine-grained, very micaceous, argillaceous sand, with many shells and shell fragments. This is one of the good fossil localities of the Matawan.

MECHANICAL ANALYSIS

Sample	7.185 gm.	
Treated with dilute hydrochloric acid.		
		Per cent of sample
Lime-free residue		94.8
Lime (by difference)		5.2
Total		100.00
		Per cent of lime-free residue
Sands		80.7
Clay		18.9
Total		99.6
		Per cent of total sands
Coarse sand		0.3
Medium sand		2.6
Fine sand		5.1
Very fine sand		60.9
Extra fine sand		30.0
Total		98.9
		Per cent of very fine sand
Light		93.3
Heavy		6.9
Total		100.2

MAGNETIC SEPARATION

Attracted at 3000 ohms (mainly glauconite).....	4.3 ¹
Attracted at 1000 ohms (mainly glauconite).....	36.9 ¹
Attracted at full current.....	13.0
Non-magnetic	28.7 ²
Magnetite	17.4 ³
Total	100.3

DESCRIPTION OF PRODUCTS

A. UNDER THE HAND LENS

I. Coarse Sand

- (a) Three grains subangular to very well rounded, frosted.
- (b) Four grains likewise rounded but glossy and slightly pitted as though corroded by solution.
- (c) Four grains rough, pitted, *angular*, corroded, with much greenish-black clay in the irregularities of the surfaces. This shows a transition from (b), suggesting that most of the grains were originally rounded. (a), (b) and (c) are of glassy quartz.
- (d) *Sugary* quartz, rough, fissured, pitted and filled with green *glauconitic* and black clay *stain*. Four grains.

¹ Glauconite (see microscopic study below) may be taken about 37.5% of heavy=2.5% of very fine.

² Mainly carbonaceous matter.

³ Note the unusually high magnetite.

(e) Three very dark grains apparently filled with black clay and green glauconite stain. These are like the grains in sample 13 which are believed to be *secondary* quartz. Under the microscope these grains show homogeneous polarization and much of the included matter appears to be mica.

II. Medium Sand

Mainly like the coarse with the following differences:

- (a) The smaller grains instead of being rounded, are sharp, fresh, *angular*, evidently primarily so. Rounded grains are, however, still very abundant.
- (b) Dark minerals (mainly magnetite and mica) begin to appear.
- (c) There are more of the stained quartz grains.

III. Fine Sand

Characterized:

- (a) By the appearance of rather abundant, rounded, yellow-green *glauconite* grains.
- (b) By the *angularity* of the quartz.
- (c) By the freshness of the quartz, i. e., little stained sugary quartz and *no secondary* grains with clay inclusions were observed.
- (d) By the abundance of carbonaceous fragments.
- (e) By the fact that there appears to be little, if any, increase in the proportion of dark minerals, except glauconite.

B. UNDER THE MICROSCOPE

I. Very Fine Sand

(1) Light

Greenish-gray with much mica.

Quartz : feldspar = 95 : 5.

No distinct secondary quartz or feldspar with black clay inclusions, though black clay has penetrated into the fissures of a few grains, especially of feldspar. Glauconite staining occurs but is not abundant. There is no limonitic staining. There are here, as in sample 4, some of the rounded, clay-like grains showing a faint aggregate polarization, apparently transition forms to glauconite. Glauconite in rounded grains mostly full of round black granules.

(2) Heavy

The heavy minerals are:

Glauconite, chlorite, muscovite, epidote, tourmaline, garnet, amphibole (colorless), staurolite, zoisite, rutile, serpentine, enstatite, zircon, kyanite.

The glauconite is full of black granules. The chlorite and muscovite are in the same condition.

II. Extra Fine Sand

Dark-gray with many minute flakes of mica.

There is a striking variation in the size of the materials. There are many small opaque spherical grains, showing a broken yellow surface by reflected light, sometimes agglomerated into small groups. They are doubtless pyrite or marcasite.

III. Clay

Much short fibrous matter. Black spherules as in the extra fine-grained portion, probably iron sulphide. Flakes of mica.

Summary and Conclusions.—The mechanical composition of this sample calls for little special comment. Its diagram shows the moderate sorting and the abrupt rise of the curve on the left with much slower drop to the right, which has been shown to be characteristic of stream deposits in

small bodies of water. This would be the conclusion even if there were not such startling, almost complete resemblance between the diagram of this sediment (H, p. 169) and that of the delta in the Lagoon of Thau (I, p. 170). The conditions I think may have been exactly those represented now by one of the submerged stream mouths forming the estuaries of Chesapeake Bay, or perhaps by the nearer shore portions of the main body of the bay near the point of discharge of some stream.

The abundance of fossils encountered here for the first time in the sediments analyzed conforms to such an assumption. Their good preservation leaves little doubt that they did live in place and were not transported.

The abundance of fossils encountered here for the first time in the this type as in sample 4.

A peculiar feature is the low percentage of heavy minerals (about 4.5%). But inspection of Thoulet's analyses from the Gulf of Lyon shows that this is so variable a feature that it must be largely dependent on the original composition of the material supplied.

The field relations of this bed require some special mention. The bed lies directly on a white Potomac clay, with a somewhat irregular surface of contact but without any evidence of a coarser basal portion. This seems to confirm the above interpretation. For any swiftly moving water with strong transporting power, or any body of water with strong wave action, must in its progress over a land surface leave a deposit of sorted coarse material, if such is available. Now, such material is available in the Potomac bed under consideration, so that if there had been strongly agitated water this coarse material must have been selected and deposited while the finer material was carried into more quiet water. Then as submergence progressed, finer material would come to overly the coarser with a gradual transition. But if a relatively quiet body of water, deriving its material laterally from some nearby stream emptying into it, transgressed over a surface of such white clay, it would, it seems to me, have only finer material to deposit and therefore put such material down as a bottom layer. Even here, however, slight wave action and therefore slight sorting might be expected, unless the shore were lined with water plants

which broke up the action of the water. The lowest part of the bed might therefore be found slightly coarser on analysis, but no such difference was noted in the field.

It is to be noted that while this bed rests directly on Potomac there must have been a preceding Upper Cretaceous transition over the region (to have furnished the glauconite which in this bed is reworked), followed again by a period of erosion which cut down to the Potomac beds.

Minor features to be especially noted in this sample are:

- (1) The well-rounded grains of quartz in the coarser sizes.
- (2) The strongly marked solution surface on most of the coarser grains.
- (3) The secondary quartz grains.
- (4) The grains representing a transition stage between clay and glauconite.
- (5) The abundant black mineral granules in the glauconite and in the micas.

SAMPLE NO. 12 (FIG. L, p. 169)

Serial number : 3.

Field number : 11-9-28-1911.

Formation : Monmouth.

Locality : Sassafras River.

Appearance : Loose, coarse, gravelly, dark greenish-brown sand with crumbly lumps of sand in a matrix of grayish-white clay. The loose sand appears to be mainly rounded grains of yellow-stained quartz.

MECHANICAL ANALYSIS

Sample	9.235 gm.	
		Per cent of sample
Fine gravel	4.2	
Sand	71.1	
Clay	25.2	
Total	100.5	
		Per cent of total sands
Coarse sand	25.2	
Medium sand	49.4	
Fine sand	16.2	
Very fine sand	6.0	
Extra fine sand	3.0	
Total	99.8	
		Per cent of very fine sand
Light	14.0	
Heavy { Rejected at 2000 ohms	1.8	
{ Attracted at 2000 ohms (glauconite)	74.5	
Total	90.3 ¹	

¹ It was at first not intended to weigh the products of this separation. Thus they were not weighed till after microscopic study when some had been lost. They are given to show the great dominance of glauconite (the portion attracted at 2000 ohms).

DESCRIPTION OF PRODUCTS

A. UNDER THE HAND LENS

I. Fine Gravel

Some of the 22 grains are quite well rounded, others very angular, but even the angular ones show a glossy surface that suggests solution. They are all deeply stained with yellow ocher.

II. Coarse Sand

The glauconite is abundant in this portion, showing its original botryoidal form, but almost all but the smallest grains appear more or less completely ocherized. The quartz grains are like those in the gravel. Of special significance is a grain *half feldspar, half quartz* indicating origin from a nearby granitic rock. The proportion of rounded grains is less than in the gravel.

III. Medium Sand

Differs from the preceding in that more of the glauconite is worn.

IV. Fine Sand

Contains some mica but apparently not yet any heavy minerals.

V. Very Fine Sand

A general dark-green appearance with dark limonitic grains.

VI. Extra Fine Sand

The dark-brown limonitic color predominates in this.

VII. Clay

Yellow, limonitic.

B. UNDER THE MICROSCOPE

I. Very Fine Sand

(1) Light

Quartz : feldspar = 75 : 25.

Though most of the feldspars, like the quartz grains, are stained by ocher, the large proportion of fresh, unweathered feldspars is striking.

(2) Heavy

(a) Attracted at 2000 Ohms

Almost all *glauconite*, so that the identification of other minerals is difficult. The following were recognized: muscovite, epidote, serpentine, staurolite (?). Most of the glauconite is quite opaque, at best only cloudily translucent at the borders.

(b) Rejected at 2000 Ohms

Dominant.—Muscovite, enstatite, zircon.

Rarer.—Rutile, garnet, biotite, tourmaline, serpentine, apatite (?).

II. Extra Fine

Many flakes of brown, granular ocher.

III. Clay

The clay appears all granular, the usual fibrous portions which characterize the clay not having been recognized. This probably means that it is mostly secondary limonitic matter, not primary clay.

Summary and Conclusions.—(1) It is especially to be borne in mind that there is really almost no clay present, the abundant material classified under this head being probably almost all limonite.

(2) The diagram offers little of special interest. It is moderately well sorted sand, intermediate between lagoon and marine conditions, but nearer those of a lagoon. The usual absence in the Monmouth of the black clay peculiar to the Matawan combined with this fairly good sorting suggests more open water conditions, that is, probably a more general submergence. The most striking feature of the sediment is its great coarseness which, with its regular bedding and uniform lateral extension in the field, points to near-shore conditions for its formation. This leads to the third important feature to be noted, namely,

(3) The fact that in such shallow near-shore conditions glauconite is present. This is so contrary to the usual assumption of quiet waters for the formation of glauconite that one is inclined to believe that the glauconite is reworked from adjacent shore bluffs, but in that case evidence of wearing of the glauconite grains would be expected. Still the author does not believe that any modern glauconite-bearing sediment as coarse and as free from clay as this has been found.

Another possibility which suggests itself is that the sediment was formed in deeper water but swept by a strong current. While there are no data for the transporting power of currents in open water it is doubtful that so much of the "coarse" sand could be transported by such means. Moreover, the regularity of bedding in the field is against that assumption.

It is a peculiar sediment and all the more interesting, not only for its peculiarities, but also because in its general appearance in the field it is so typical of the Monmouth formation of the Chesapeake Bay region.

(4) Finally, an important feature is the high percentage of *feldspars* and their appearance of freshness. Their freshness opposes the belief that the material is reworked from an older sediment, while their high proportion, as well as the grain of combined quartz and feldspar noted in the description of the coarse sand, point to origin from nearby.¹

¹For the percentage of feldspar in different deposits see Mackie, Wm. The sands and sandstones of E. Moray, Trans. Geol. Soc. Edinburgh, 1896, vol. 7, p. 149.

SAMPLE NO. 13 (FIG. M, p. 169)

Serial number : 1.

Field number : 1-9-14-1911.

Formation : Rancocas (?).

Locality : South of Middletown, Delaware.

Appearance : Coarse loose sand in a weak black clay matrix; weathering shows it to be full of marcasite.

MECHANICAL ANALYSIS

Sample	9.257 gm.
	Per cent of sample
Sands ¹	76.8
Clay	22.0
Total	98.8
	Per cent of total sands
Coarse sand	9.5
Medium sand	60.3
Fine sand	18.1
Very fine sand	6.9
Extra fine sand	5.2
Total	100.0
	Per cent of very fine sand
Light	91.4
Heavy	5.1
Total	96.5

DESCRIPTION OF PRODUCTS

A. UNDER THE HAND LENS

I. Coarse Sand

Grayish-white. Almost all grains are colored by black clay occurring in the irregularities of the surface. The solution effect on these grains is evidently so strong that it almost obscures the original form, producing a glossy but very irregular, deeply-pitted surface. Most of the grains are of clear quartz but a few are granular in appearance and stained dark grayish-black. A very few show dirty greenish staining. In spite of solution effects it is evident that the majority of the grains were originally rounded though there are some that as clearly indicate an original angular form.

II. Medium Sand

Much like the coarse sand but with fewer rounded grains, few of the dark-gray granular grains and with some heavy minerals (garnet, rutile ?, a black, very glossy mineral not magnetite), etc. A little marcasite in the cleavage of some grains but no marcasite nodules were found.

III. Fine Sand

Like the medium sand but with more heavy minerals (rutile especially conspicuous) and the grains still more generally angular.

B. UNDER THE MICROSCOPE

I. Very Fine Sand

(1) Light

Quartz : feldspar=95 : 5.

Feldspar much decayed. Of special interest are the dark-gray grains of quartz, which appear to be full of black flakes like the argillaceous matter which forms the matrix of the bed; these quartz grains polarize as units. When they are crushed the fragments

¹ By summation of parts.

are found still to contain the black flakes which proves that the black material is really on the inside. Grains of the same kind were picked out of the medium-grained sands (the dark-gray grains mentioned in the hand-lens description). Some of these were composed of colorless quartz, others showed a humus-brown color throughout. They also polarized as units and on crushing showed the same dissemination of the black flakes throughout the original grain. I have, therefore, concluded that these grains are secondary, that is, formed after the deposition of the bed.

(2) Heavy

Almost half of this portion appeared to be *magnetite*, and red *garnet* is very common. *Rutile* is also common.

Rarer.—Epidote, tourmaline, pyroxene, chlorite, enstatite, zircon, sillimanite (?). Some of the garnet and epidote are well rounded.

II. Extra Fine

A very dark, brownish-gray, fine-grained, very slightly micaceous powder. This material is finer than in most of the samples because it contains much that usually goes into the slit. Under the microscope it shows much argillaceous matter in brown floccules.

Many small, irregular roundish to perfectly spherical nodules of *marcasite*. Some of the black nodules of *marcasite* are fringed by a brown, translucent, isotropic substance. In other cases they are made up of an agglomeration of tiny spherules in a matrix of such substance. There are some chloritic, perhaps a few glauconitic fragments; in addition of course many quartz and feldspar grains.

III. Clay

Dirty brownish-gray. It contains much of the dirty, fibrous, polarizing material besides the usual amorphous brown flocculent matter, and some mineral grains.

Summary and Conclusions.—This is a very peculiar and distinct sediment and must be the product of special conditions which are only partly brought out by the above study, so that no attempt will be made to do more than indicate some of the factors in its origin. The peculiar impression it makes is probably due mainly to its coarseness, its truly black color, its very friable condition, due perhaps to the fact that the black "clay" binder (it is not abundant enough to form a matrix) is not true clay, *i. e.*, not colloidal, or else that the peculiar conditions under which it was deposited destroyed its coherence. The abundance of sulphide (presumably *marcasite*) and coarse brackish-water features of the fauna sustain the impression of something unusual. One would say a very stagnant lagoon, estuary or delta, yet the diagram (M, p. 169) does not bear this out, for it suggests good sorting, quite as good, excepting for the clay, as in the open-water marly Monmouth (sample 11, K, p. 169). But in considering the sizes involved it is noticed that there is in all the diagrams presented not another one (even marine beach sand) which has the maximum in a portion so coarse as the medium sand ($1\frac{1}{2}$ mm.) It might be

that a swift stream could deposit in its delta a sediment with so much coarse material, but the type of diagram is too far from that of a delta to make such a belief tenable.

Before attempting to adjust these facts some of the peculiarities observed under the microscope should be considered. Foremost among these are the grains of what are called secondary quartz. Humus waters are known to have a strong solvent action on silicates and on silica. The brown, humus coloring of some of the grains of secondary quartz and the envelopes of the same color surrounding some of the marcasite spherules suggest the presence of such matter; yet no carbonaceous matter was found in the bed. Moreover, while decaying animal matter might have precipitated the marcasite, the apparently disseminated occurrence of these spherules and the fact that in the field they were not seen to be concentrated about the fossils seem to demand some other agent. The assumption of algæ would meet these conditions and be in harmony with the general stagnant-water character of the bed. If, however, the precipitation of iron disulphide is attributed to the animal matter the secondary quartz might be accounted for by the former existence of a swamp overlying these beds from which descending humus waters could have produced the secondary quartz, but the knowledge of these processes is still too imperfect to permit of a very trustworthy explanation.

While the assumption of origin in place of the quartz grains described seems to be demanded by their internal structure it should be noted that this interpretation meets with a serious difficulty, that is, the outer form of the grains. This form is that of the normal quartz grains in the deposit, in part rather rounded, in part angular. If they formed in the midst of the bed it does not seem as though they could have found the space to grow freely; they should rather have involved adjacent grains, and the ends of the other grains so involved should give the secondary grain a rough agglomerated appearance. On the other hand, if they formed in some organic mold there should be more regularity and uniformity to their shape. Field sections throw little light on the problems as there are only a couple of feet exposed both vertically and laterally; the only character noted is the presence of fine horizontal clay films on

which fossils are particularly abundant, indicating fluctuations in the conditions of deposition.

In summing up it becomes necessary to neglect the diagram entirely and to rely on the general physical characters. Here the evidence of much humus, the high sulphide content, and the peculiarities of the fauna are indications of a very stagnant, brackish body of water, perhaps surrounded by swamps or filled with disseminated algal growths. The region was evidently near enough to some stream to be affected by fluctuations in its transporting power resulting in the separation of sand layers by clay films and layers of fossils. But the best explanation for the peculiarities of the diagram of this sediment is in just these secondary grains. It is their development that can account for the coarseness of the sand, and one may even assume that they had reached a certain average size, between 1 mm. and $\frac{1}{2}$ mm., to account for the maximum in that size. This interpretation is very hypothetical, but it is the best combination that presents itself for the various partly conflicting factors that are involved. The questions presented require more detailed and extensive study.

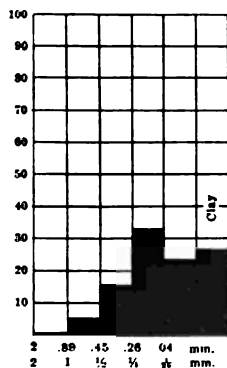
GENERAL SUMMARY AND CONCLUSIONS

The special features of each sediment having been discussed, it remains to sum up the conclusions arrived at and to give a general review of the glauconite in the different samples.

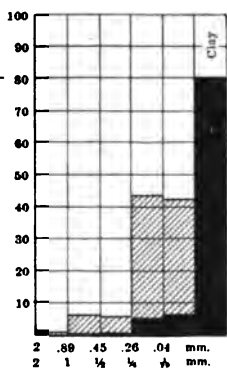
CLASSIFICATION OF THE SEDIMENTS

In the discussion of the 13 sediments studied in this paper three types have been differentiated: (1) The delta type; (2) the estuarine or lagoonal type; (3) the open-water glauconitic type. The character of each may be briefly summarized as follows:

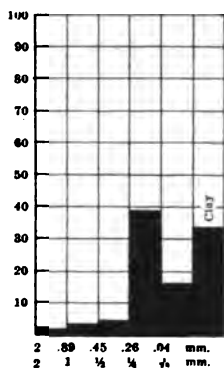
The delta type has as its foremost characteristic the large proportion of a wide range of sizes of sand which a single sample taken from it contains. In the diagram this is expressed by a broad curve with no pronounced maximum. This character is not very markedly affected by the



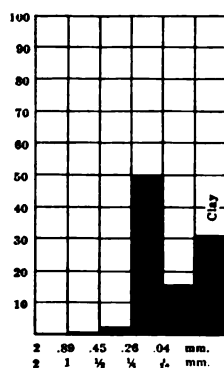
A.—Sample 1. Magothy formation, Betterton.



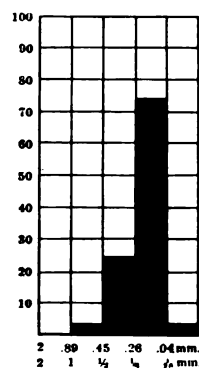
B.—Sample 2. Magothy formation, Betterton.



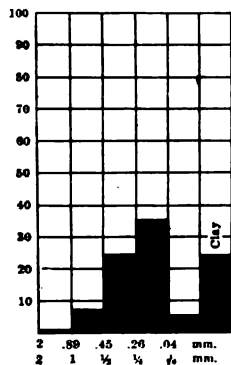
C.—Sample 3. Matawan formation, C. & D. Canal.



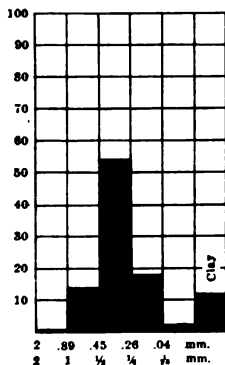
D.—Sample 4. [Same as 3.]



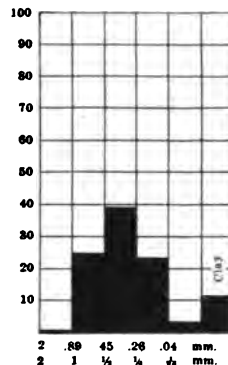
E.—Sample 5. [Same as 3.]



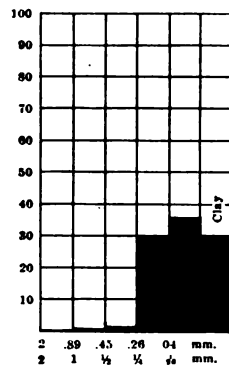
F.—Sample 6. [Same as 3.]



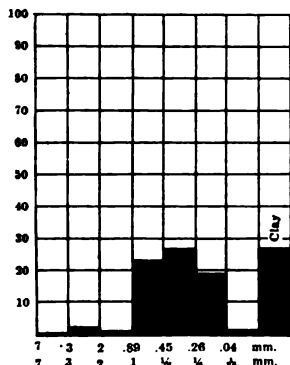
G.—Sample 7. Matawan formation (calcareous), Camp Fox, C. & D. Canal.



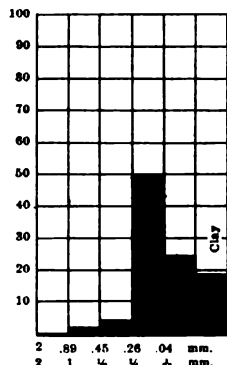
H.—Sample 8. [Same as 7 (non-calcareous).]



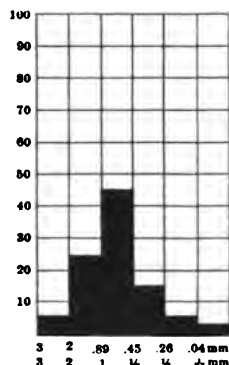
I.—Sample 9. Matawan formation, Grove Point.



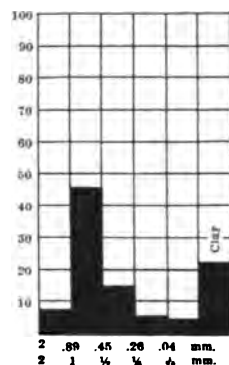
J.—Sample 10. Top of Matawan or base of Monmouth, Sassafras River.



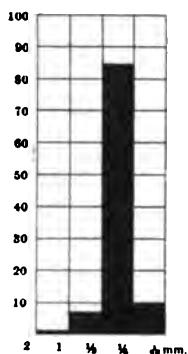
K.—Sample 11. Monmouth formation, Seat Pleasant.



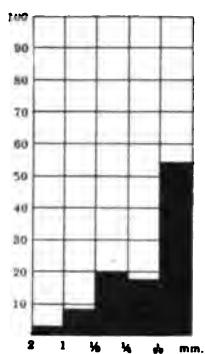
L.—Sample 12. Monmouth formation, Sassafras River.



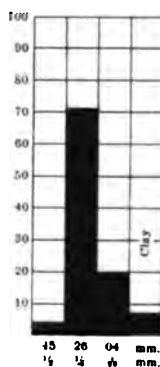
M.—Sample 13. Rancocas formation, near Middletown, Del.



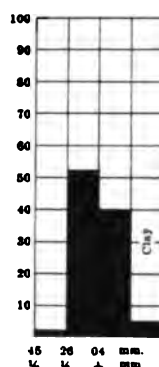
A.—Fresh beach sand. East Indies. Mohr, No. 213.



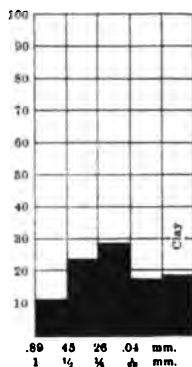
B.—Deeply weathered beach sand. East Indies. Mohr, No. 250.



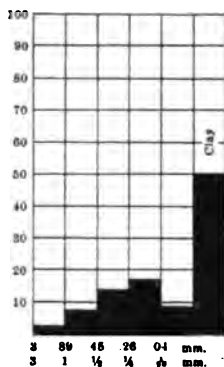
C.—Typical offshore sediment, Gulf of Lyon. Thoulet.



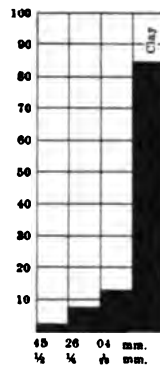
D.—Off Rhone Delta. Thoulet, B40.



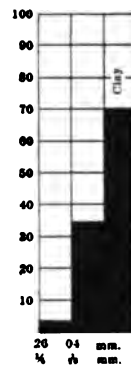
E.—Lagoon of Thau. Sudry, No. 123.



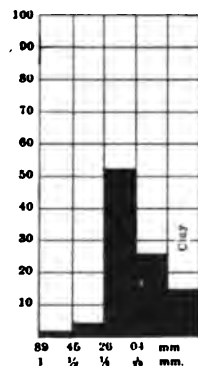
F.—Same as E but finer. Sudry, No. 25.



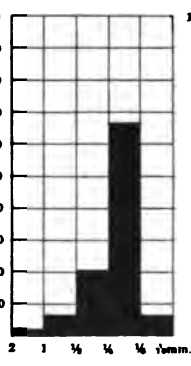
G.—Fine lagoonal sediment. No. 49.



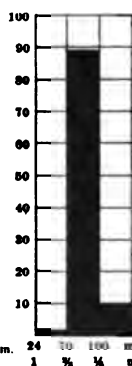
H.—Same belt as G, but in reeds. Sudry, No. 2.



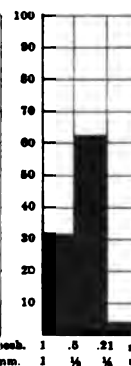
I.—Delta in lagoon. Sudry, No. 110.



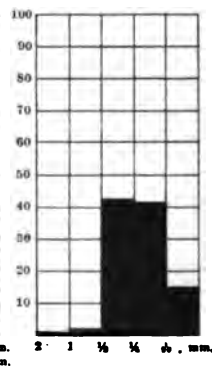
J.—Dune sand (average). Udden.



K.—Dune at mouth of Indus. Oldham.



L.—Sahara sand. Thoulet.



M.—Stream alluvium. Mohr, No. 696.

ratio of sand and clay in the sample, a bed high in clay and low in sand containing almost as large a proportion of coarse material in the sand as does a distinctly sandy bed. With this wide range in the size of the sands there probably also goes, generally, a high ratio of heavy to light minerals, and to a certain extent an abundance of magnetite (*cf.* samples 1-3).

This statement concerning the magnetite is made somewhat doubtfully because there is definite evidence for it only in sample 1; it may be true also of sample 2), but there the mica is so dominant as to leave the percentage of minerals, more certainly classed as heavy by their settling properties, relatively small, and it may also have caused the magnetite to be overlooked. Abundance of magnetite is, moreover, characteristic of sample 11, which must be regarded as a rather typical example of the estuarine type. In the differentiation, at least of two such closely related types, therefore, the proportion of magnetite must not be given much weight. A high percentage of heavy minerals in general seems more likely, however, to be a characteristic of the delta type.

A great abundance of carbonaceous matter is another characteristic of this type, for which, however, the evidence given in these analyses is only qualitative. With this goes the formation of pyrite, or more probably marcasite, which, as will be shown later in the discussion of glauconite, is an alternative product to glauconite, formed in the presence of abundant organic, especially humus matter. It should be noted, however, that as abundant humus matter is also characteristic of many estuarine deposits, so marcasite is found also in these (samples 11 and 13). Furthermore, since the recognition of an opaque mineral of this kind under the microscope is difficult, it is probable that it has been overlooked in some samples in which it might be found if it were especially sought.

Finally, the form of occurrence in the field is very important for the differentiation of this type, which is characterized by thin-bedding, by extreme difference in the proportion of sand and clay in adjacent beds, and by the occurrence of thin sand partings representing, doubtless, temporary stream floods. Moreover, in the argillaceous beds the abundance of mica is usually a conspicuous feature in the field, little streams of carbon-

aceous matter occur, and the high percentage of magnetite is sometimes noticeable.

Under the glauconitic-sand type only the three samples, 7 and 8 from the Matawan, and 12 from the Monmouth, will be considered. Foremost among the characters of the glauconitic sands is their coarseness and the accompanying low percentage of clay. The figures for the clay unfortunately do not bring this out as clearly as they should, on account of the great amount of ocherous matter present, which tends to be separated with the clay. With these striking characters goes better sorting of the sands, that is, a more sharply defined maximum in the diagram, and generally a lower proportion of heavy minerals (the glauconite having been deducted in these samples on the assumption that it was formed in place).

What is called the estuarine type lies between these two other types, and therefore, naturally, shows transitions to both of them. Thus, sample 5, the sandy yellow glauconite bed in the Matawan, would, but for its associations, be classed unhesitatingly with the group of glauconite sands. Indeed, an estuary or lagoon from its very nature can readily become an open body of water, and there is no reason why this may not be assumed to have happened here. There is the characteristic sorting of the sands, the only difference from the other glauconitic sands being the greater fineness of the maximum size; but there is no reason for believing that such a character cannot belong to a typical glauconite sand; and the limited number of analyses of typical glauconite sands does not justify making a contrary generalization.

The most conspicuous feature of what is called the estuarine or lagoonal type is of course the characteristic black, argillaceous appearance of the Matawan, by which it is so readily recognized in the field. The cause of this coloring is one of the unsolved problems in the study of these deposits. In the normal samples of this type the clay itself, when separated, is of the ordinary blue-gray color. The black color cannot be attributed to organic matter since that is, in the most characteristic samples, not unusually abundant, and moreover, it may be seen from the Magothy that the pres-

ence of carbonaceous matter does not tend to give that color but rather the blue-gray. Perhaps the color is in some way the result of the characteristic on which these beds have been differentiated, the mixture of an abundance of fine-grained sand with a moderate amount of clay, which results from the wide range in the size of the material forming the bed. That is to say, these beds being predominantly fine-grained should consist mainly of extra-fine sands with much clay. But as a matter of fact, while most of them are very high in extra-fine sands and contain much clay, they contain, in many cases, even more very fine sands, and usually also a considerable proportion of some of the coarser sizes. The most marked exception to this general wide range in sizes is sample 5, which, as just stated, is really a glauconitic open-water deposit. Sample 6, which is closely associated with sample 5, shows much less divergence from such composition; while all the others satisfy reasonably well the description just given. Sample 9 diverges from the normal estuarine type again in the other direction, that is, towards the delta type; but its affinities with this type were already pointed out in the summary and discussion of it. To a somewhat less extent the same is true of sample 11, as was also explained in the summary and discussion there. These divergences all serve merely to bring out the intermediate character of the estuarine type.

In conclusion, if the distribution of the three types of sediments as defined in the different formations is considered it is found that the samples studied from the Magothy are distinctly of the delta type. In the Matawan and in the Monmouth both the estuarine and the open-water glauconitic types are found. This is not surprising. Even without the evidence afforded by sample 10 for the Monmouth we know and might expect that in both periods there was transgression, and this transgression might well be estuarine in its basal portion. Thanks to the good section afforded by the Chesapeake and Delaware Canal, the relation of samples 4 to 8 is clear, and it is in conformity with this relation that the higher portion represented by samples 7 and 8 should be of a deeper-water type than the lower portion (samples 3 to 6). The stratigraphic relation of

the two Monmouth samples 11 and 12 is not so clear, but it is perfectly reasonable that sample 11 should be of the estuarine and sample 12 more of the deeper-water type whether they are the product of different more or less contemporaneous facies, or of successive stages in a transgression.

There is a general feature which was not taken up in the discussion of the individual samples because the facts were not sufficiently significant. This is the mineral content of the beds. It was thought that some light might be thrown on the source of the material by the rarer minerals: but their most striking characteristics are their similarity in different beds and their apparently nearby origin. Moreover, their resemblances are not only with each other but extend far beyond to such sedimentary beds in general as have been studied from this point of view. Many of the same minerals will be found to prevail, for instance, in the materials studied by Cayeux and Thoulet,¹ or in other such studies as listed by Andrée.² Even common experience teaches the prevalence of magnetite in stream-borne sands; and epidote while less easily recognized is probably almost as common, is in fact said by Van Hise³ to be one of the characteristic minerals of sedimentary rocks. Equally, or even more frequent are chlorite and muscovite. Tourmaline, rutile, and zircon survive in almost all sediments if there is any source for them. The persistence of enstatite in these samples is apparently a more local character but can be accounted for by the occurrence of the mineral in the rocks of the neighboring Piedmont region. It tends to bring out, however, the predominance of minerals that might at least be of nearby origin, in these sediments. It is this fact which obscures other evidence and makes it possible to say only that the Piedmont region appears to be the source of most of this material. But in this connection two important facts should be noted. One is that the Piedmont region is petrographically so

¹ Cayeux, Lucien, Contribution à l'étude micrographique des terrains sédimentaires. Mém. de la Soc. Géol. du Nord., T. iv-2.—Thoulet, J., Etude bathylithologique des côtes du Golfe du Lion. Annales. de l'Inst. Océanograph. T. iv, Fasc. 6, Paris, 1912.

² Andrée, K., Sedimentbildung am Meeresboden. Geol. Rundschau. vol. 3, 1912, pp. 324-338.

³ Van Hise, C. R., A treatise on metamorphism. Mon. U. S. Geol. Survey, No. 47, 1904.

varied that it could furnish almost any of the more usual rock-forming minerals; the other is a fact that is, perhaps on account of its unwelcome character, all too generally ignored in work of this kind, namely that the older sedimentary rocks—limestones, shales, or sandstones—contain heavy minerals just as do the rocks being studied, and that a region of sedimentary rocks is not going to yield, at least at a distance, fragments of limestone and shale, but rather the mineral grains that were included in the limestone and shale. Thus the problem is seen to be a very complicated one, in which only the most general results are readily obtained. If this side of the work is to be developed it will probably be necessary either to find unusual minerals and trace them, or else to differentiate by a close mineralogic study varieties of common minerals, such as feldspars, augites, hornblendes, or even quartz, as Mackie has done,¹ and then trace down to its source the particular variety thus identified. This requires, however, close study not only of the sediments but also of the rocks from which their minerals may have been derived, and this becomes a long and arduous problem. Without such work the study of mineral grains in sedimentary rocks does not, in most cases, yield much of value.

It will have been noted that in all the sediments studied the coarser sizes of sand had a glossy pitted surface which seemed plainly to indicate solution of the grains after deposition. This phenomenon appeared so general that it cannot be connected with the particular composition of the bed. Evidently the ordinary circulating ground water is the agent. The chemistry of the process is not understood, though humus waters are supposed to be particularly effective. According to the more recent theories, which deny the existence of humus acids, this is probably due to the carbonic acid.

More limited in its observed occurrence in these samples is the deposition within the sediment of quartz from solution. The evidence for this appeared most convincing in sample 13, but associated with deposition of silica there is here to an unusually pronounced degree the same solution of silica as noted on the quartz grains in most of the other

¹ Mackie, Wm., The sands and sandstones of E. Moray. Trans. Geol. Soc. Edinb. vol. 7, 1896, pp. 148-172.

samples. While the coexistence of solution and deposition of the same substance in a bed seems at first inconsistent it may nevertheless be in conformity with the recognized principle of chemistry that among particles of substance in a medium in which they are partly soluble the larger particles will tend to grow at the expense of the smaller. Or the nuclei around which deposition took place may have been in some way chemically different. Whether these supposed secondary grains have definite nuclei and what these nuclei are was not determined, though thin sections might throw some light on the question. The peculiar completeness in the form of these grains was noted and seems to be the fact most inconsistent with the hypothesis of their secondary origin. That strong chemical action is indicated by the abundant deposition of sulphide in the bed should be borne in mind in this connection.

To conclude the general summary it may be said that in all the samples, no matter what the form of the coarser sizes of sand, there is never any appreciable amount of rounding below the fine-sand size (*i. e.*, $\frac{1}{2}$ mm. to $\frac{1}{4}$ mm.).

THE GLAUCONITE

Collet's¹ little manual on marine sediments contains so complete and up-to-date a summary by a specialist on glauconite, contributing even some hitherto unpublished data, that it is unnecessary to enter into a general discussion.

But perhaps by way of preface, since others may, like the writer, have considered glauconite a comparatively rare mineral, it will be worth while to draw attention to its distribution in marine sediments. So common is it, indeed, that Collet considers it necessary to explain its absence rather than its presence.² It is found more or less along the coast of all the oceans at depths varying from 91 m. along the northern Atlantic coast of the United States to 3512 m. in the Indian Ocean. In the red clays which cover the greater depths, it is, for some undetermined reason, absent.

¹ Collet, L. W., *Les dépôts marins*, pp. 132-194, 303-306. Paris: Octave Doin, 1908.

² Collet, pp. 303-306, addenda on the red clays.

Of the three forms of glauconite differentiated by Collet, all three are found in these sediments. The grains which in this paper have been described as botryoidal are those called *casts* by Collet, that is, they are believed to owe their form to their origin within the shells of Foraminifera. A very few grains were noted that had the form of other small shells, but the shells were not further determined. The description of the products shows that this form of glauconite occurs mainly in the medium and fine sands, occurrences in the coarse sand having usually the appearance rather of secondary agglomerations of smaller grains, while only few if any such grains without signs of wear are found in the very fine sands. This distribution means a range of size pretty well within the limits of 0.3 mm. to 0.9 mm. diameter. Collet¹ gives an upper limit of 1 mm.

The second kind of grain defined by Collet is simply a grain showing no trace of an original mould. To this category belong the rounded grains which prevail in the very fine and finer portions of sediments with primary glauconite, and which as *reworked glauconite* enter into other beds. It is generally agreed that they are derived through the rounding by attrition of the glauconite casts.

To Collet's third type, the fragmentary glauconite, belongs what is here called glauconite stain; that is, the glauconite adhering like clay to the outside or filling the fissures of mineral grains.

Concerning the origin of glauconite, Collet's own conclusion that the processes are still very little understood may be emphatically cited. But the facts of observation at least give much evidence as to the conditions under which it takes place.

It is generally believed that a certain amount of organic matter is essential to the process, but an excess of it seems, on the other hand, to interfere. Collet² gives the formula, which appears to be generally accepted, by which decomposition of organic matter precipitates FeS (p. 171). As he explains, this FeS is believed to be capable of giving up its iron directly to silicates to form iron silicates, but an excess of organic matter interferes with the process and thus leads to the accumulation

¹ Collet, L. W., Op. cit., p. 133.

² Collet, L. W., Op. cit., pp. 169, 170.

of pyrite as noted above in this summary. Whether this is due to the presence of an excess of H_2S as he mentions on page 171, or to the humus compounds (the existence of humic *acids* is now generally discredited) as in lake deposits¹ has not been proved; recent observations tend to show that certain special bacteria are factors both in the precipitation of FeS and in its oxidation to FeS_2 ; but whatever the process the fact may be accepted that in the presence of abundant organic matter in fairly quiet waters FeS_2 is formed. Collet presents for the steps of the process of glauconite formation an explanation,² somewhat simplified from that of Murray and Renard, based on elaborate and extended studies of his own. In both theories, to start with, a colloid is assumed. Murray and Renard conceive of the production of colloidal silica by the action of sulphuric acid derived from the oxidation of the FeS present, while Collet starts merely with the colloidal matter of clay. This, through the processes of sedimentation, has naturally come to fill the foraminiferal shells present. The Al of the clay is first exchanged with Fe , and this new compound combines with potassium present in the sea water, and also with some water, to form the glauconite. In support of this theory Collet finds many intermediate stages from grains having the appearance of fresh clay to grains turned increasingly deep brown by taking up iron. The writer's observation of grains having the form of glauconite, the appearance of clay, but an aggregate polarization, was made without any knowledge of Collet's observations and is therefore independent testimony in support of this view.

The occurrence of similar material in sample 11 (p. 160, above), which contains FeS_2 (marcasite ?), is perhaps more questionable. Moreover, on reviewing the sediments as a whole, the writer is not inclined to consider the little clay accretions or nodules in the sulphide-bearing samples 1 and 2 as related to the glauconite. On the contrary, in view of the impregnation of organic fragments with some iron salt (probably marcasite) that is shown to have taken place there, it seems more probable that this same mineral is responsible for the clay nodules. In fact, these questions can be

¹ Collet, L. W., Op. cit., pp. 178, 179.

² Collet, L. W., Op. cit., p. 176.

solved only by getting different stages in the processes involved, and perhaps by chemical analysis, and the present observations are not considered as sufficiently extended to give ground for interpretation of the facts observed.

In view of the very undeveloped state of knowledge of the actions of colloids, the uncertainty about the processes involved in the formation of glauconite is very comprehensible. The known power of colloids to absorb without chemical combination variable amounts of different substances may also account for the indefinite composition indicated by analysis. Against this apparent variability Collet's protest¹ that most of the samples analyzed were not made up of perfect glauconite seems invalid since his only criterion was fresh green color and, and there is no evidence that within material of this green color there are not imperceptible variations in degree of what he himself (p. 176) calls "glauconitization." Indeed, the wide difference in tone between samples of glauconite from different localities would seem to indicate that there is such a variation. The only analysis that could by itself definitely be set up as establishing the composition of glauconite would be of good crystals of the substance, but recognizable crystals identified as glauconite are so rare and so small when they do occur that chemical analysis has not been possible.² Moreover, it may well be that glauconitization does not tend at all toward the formation of a single definite compound and that different glauconites are only different members of a series like the chlorites to which they are by some supposed to belong, or like other micas. That this is probable is indicated by Collet's discussion³ of the crystal identified by Cayeux, which he shows has different optical properties from others that have been described.

However, there is strong evidence in favor of Collet's view of the process. First of all, it seems certain that it must start from clay, since the foraminiferal shells are sure to be filled with that substance by the progress of sedimentation. Murray's assumption of sulphuric acid to

¹ Collet, L. W., *Op. cit.*, p. 167.

² See discussion of determined crystals in Collet.

³ Collet, L. W., *Op. cit.*, p. 136.

decompose this clay, as the initiation of the process, appears paradoxical since the acid would first of all dissolve the shells forming the mould and thus allow the as yet unaltered clay at once to disintegrate.

These processes, moreover, seem to account for much of the glauconite stain, that is, the glauconite forming patches and fissure fillings on and in the grains of quartz and feldspar associated with glauconite. It is, of course, possible that glauconite is formed as a fine powder from the loose clay outside of any enclosing body, and it may well be this glauconite that forms adhering patches on the outside of some grains. But any fissure into which this could penetrate would surely be filled long before by fine argillaceous material, so that here again it seems that the glauconite in the fissures of quartz and feldspar must be formed by the alteration of an argillaceous product. The unusual thickness of some of these seams in grains of feldspar, moreover, suggests that they are more probably derived from the alteration of kaolin formed in the fissure by the alteration of the feldspar than from clay introduced from outside, since it is very improbable that an open cleavage crack of that width would exist in a grain of feldspar.

Concerning the two closely related problems of inclusions in glauconite, and decomposition of the glauconite, the present observations afford only confirmation of recognized facts. Thus the decomposition of glauconite to yield limonite is generally accepted and is conspicuously evident in the open-textured Monmouth sands. The clouded appearance of the grains of these samples under the microscope is doubtless the result of this process. The occurrence of clear, fresh-looking grains in the samples of Matawan from the Chesapeake and Delaware Canal (samples 3 and 4) is on the other hand probably due to the protective action of the clay in which they occur.

Glauconite with inclusions of black grains (pyrite or magnetite¹) were observed only in samples 8 and 11. In sample 8 it is noteworthy that the micas, too, are full of black grains. Now, magnetite

¹ The differentiation of pyrite and magnetite from each other when they are thus included in glauconite is, of course, difficult or impossible without chemical means.

is a decomposition product of biotite, and biotite may also be bleached or converted into chlorite, so that the micas present in this sample might all be derived from the decomposition of biotite. On the other hand, this bed is also sulphide-bearing. Cayeux has suggested that pyrite and magnetite might be introduced into glauconite grains subsequent to their formation, but not, presumably, in a loose sediment of this kind. Collet notes (p. 160) that those inclusions in glauconite are more common in ancient than in modern sediments. Might not these black grains, then, be magnetite produced by decomposition of the glauconite as it is produced in biotite?

There is one fact specially noteworthy about the glauconite sands of the Monmouth, that is, the coarseness of the accompanying sand. The associations in the Matawan are normal since Thoulet found it even in the narrow coastal strip of the Gulf of Lyon which he studied,¹ but its occurrence in sediments as coarse as these (in fact as the whole Monmouth and Eocene of this region) is not recognized in modern sediments. On the other hand, there is no theoretic reason against such an association.

According to Collet the feldspars associated with glauconite are predominantly basic, of about the composition of labradorite. While no specific identification of the feldspars present was made the writer's observations do not at all confirm this conclusion. The twinning characteristic of plagioclase feldspars was exceedingly rare, and the index of refraction of the feldspars was, moreover, almost invariably lower than that of the liquid (1.548) in which they were immersed, which would imply nothing more basic than oligoclase. These observations do agree, however, in that orthoclase seemed to be scarce.

The degree of weathering of the feldspars in the glauconitic samples is very variable, and is in these ancient sediments doubtless determined largely by secondary effects after their exposure. This belief is confirmed by the fact that feldspars are scarcest in those samples (9 and 11) which show clearly their derivation from the erosion of a deposit previously formed, which in the interval before it was reworked must

¹ Thoulet, J., *Etude bathylithologique des côtes du Golfe du Lion*. Annales de l'Inst. Océanograph. T. iv, Fasc. 6, Paris, 1912, p. 62, *et seq.*

have been exposed to atmospheric weathering, and at that time probably lost a part of its feldspars by decomposition. Generally the feldspars are about 10% of the light portion. The high percentage (25%) in sample 10 is probably due to derivation of the material from nearby.

The observations on mica also agree in a general way with Collet's conclusions in that mica is not abundant in the samples with primary glauconite, while in very micaceous samples primary glauconite does not occur. But this may be due mainly to the fact that the glauconitic sands are usually coarser and in such coarse sediments mica is generally more scarce. More advanced decomposition of the mica in glauconitic samples was not noticed.

BIOGRAPHY

Marcus Isaac Goldman was born in New York City, January 11, 1881. He received his schooling in the Sachs Collegiate Institute in New York and entered Harvard College in the fall of 1897, receiving the degree of Bachelor of Arts in 1901. A geologic excursion of the Harvard Summer School in 1900 from Bozeman through the Yellowstone National Park having centered his interests on geology, he devoted an additional year to the study of that subject in the Lawrence Scientific School of Harvard University and received the degree of Bachelor of Science in 1902. The following summer was spent as field assistant on the United States Geological Survey in mapping the Waynesburg and Beaver folios in the bituminous coal region of southwestern Pennsylvania. Intending to take up the economic side of geology, he entered the School of Mines of Columbia University in the fall of that year and received the degree of Engineer of Mines in 1905. But additional courses in stratigraphy and paleontology under Professor Grabau, taken while he was in the School of Mines, had awakened particular interest in that field of study to which he then devoted the following year. From July, 1906, to April, 1907, he acted as assistant to J. E. Spurr in geologic work for the American Smelting and Refining Company on their properties about Velardeña, State of Durango, Mexico, but returned as junior geologist to the United States Geological Survey in the spring of 1907. The summer of 1907 was spent in classification of public coal lands, as assistant to R. W. Stone, in the region of the upper Musselshell River, Montana, and the following summer in the same work in the Colorado Springs coal field, Colorado. In April, 1909, he went abroad to take up especially the study of the problems of the origin of sedimentary rocks under some of the leaders in that subject in European universities. A semester and a half was spent with the foremost student of those questions, Professor Johannes Walther, of the University of Halle, Germany, where he occupied himself especially with the study of the Upper Cretaceous transgression in Saxony and the adjacent region of

Bohemia. In February, 1910, Professor J. Thoulet was kind enough to receive him as a guest in his laboratory at the University of Nancy, France, where he learned the methods used in the analysis of sediments. At Professor Walther's suggestion, and largely through his efforts, he was enabled to spend several weeks in April and May, 1910, at the Zoological Station at Naples where, besides gaining some general acquaintance with the conditions of life of marine organisms, he began observations on the effects of the work of burrowing and mud-eating marine animals. A previous arrangement with Professor Thoulet called him away to assist in the collection of bottom samples in the western part of the Gulf of Lyon. The rest of the summer of 1910 was spent in field excursions with Professor Grabau and geologists of the Scottish Geological Survey in Scotland, and in attending the International Geologic Congress at Stockholm. The following winter was passed in Paris, especially in the study of the Cretaceous paleontology at the Sorbonne and the School of Mines, with field trips in the Tertiary of the Paris Basin, a brief visit to the Cretaceous of southeastern England, and some particularly valuable excursions with Professor Cayeux and his students to various parts of northern France. In May, 1911, he returned to enter The Johns Hopkins University and take up the study of the Upper Cretaceous of Maryland, of which some of the results are presented in this dissertation.

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